Quantum Optics and Photonics Division
Fachverband Quantenoptik und Photonik (Q)

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Overview of Invited Talks and Sessions

(Lecture halls A320, E001, E214, F342, and F442; Poster Empore Lichthof)

Invited Talks

Q 2.1	Mon	11:00–11:30	E001	**Interferometry with Bose-Einstein Condensates for inertial sensing** — •Sven Abend, Christian Schubert, Matthias Gersemann, Ernst M. Rasel, QUANTUS-QGYRO Teams
Q 9.1	Mon	17:00–17:30	A320	**Compressibility and the equation of state of an optical quantum gas in a box** — •Julian Schmitt
Q 10.1	Mon	17:00–17:30	E001	**Maiman's ruby laser reborn as diode pumped cw laser** — •Walter Luhs, Bernd Wellegehausen
Q 17.1	Tue	11:00–11:30	E001	**Thin-film lithium niobate waveguides for integrated quantum photonic technologies** — •Francesco Lenzini, Emma Lomonte, Wolfram Pernice
Q 18.1	Tue	11:00–11:30	E214	**Atoms coupled to nanofibers: from topological phases to correlated photon emission** — •Beatriz Olmos
Q 36.1	Wed	14:30–15:00	E214	**BMBF-Förderprogramm: Wissenschaftliche Vorprojekte** — •Bernhard Ihrig, Johannes Mund
Q 47.1	Thu	11:00–11:30	E001	**Quantum metrology with non-classical states of light** — •Michèle Heurs
Q 48.1	Thu	11:00–11:30	E214	**Using optomechanical systems to test gravitational theory – possibilities and limitations** — •Dennis Rätzel
Q 52.1	Thu	14:30–15:00	E001	**Nonperturbative Floquet engineering and Floquet-dissipative state preparation** — •Francesco Petiziol
Q 53.1	Thu	14:30–15:00	E214	**Quantum information with atomic quantum metasurfaces and integrated nanophotonics** — •Rivka Bekenstein
Q 61.1	Fri	11:00–11:30	E001	**Quantum Imaging With Nonlinear Interferometers** — •Markus Gräfe

Invited Talks of the joint Symposium SAMOP Dissertation Prize 2023

See SYAD for the full program of the symposium.

SYAD 1.1	Mon	14:30–15:00	E415	**Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems** — •Luca Asteria
SYAD 1.2	Mon	15:00–15:30	E415	**From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers** — •Patrick Rupprecht
SYAD 1.3	Mon	15:30–16:00	E415	**Particle Delocalization in Many-Body Localized Phases** — •Maximilian Kiefer-Emmanouilidis
SYAD 1.4	Mon	16:00–16:30	E415	**Feshbach resonances in a hybrid atom-ion system** — •Pascal Weckesser

Prize Talks of the joint Awards Symposium

See SYAS for the full program of the symposium.

SYAS 1.1	Tue	14:35–15:05	E415	**The Reaction Microscope: A Bubble Chamber for AMOP** — •Joachim Ullrich

SYAS 1.2	Tue	15:05–15:35	E415	**Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions** — •Rainer Blatt
SYAS 1.3	Tue	15:35–16:05	E415	**Amplitude, Phase and Entanglement in Strong Field Ionization** — •Sebastian Eckart
SYAS 1.4	Tue	16:05–16:35	E415	**All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers** — •Marvin Edelmann

Invited Talks of the joint Symposium From Molecular Spectroscopy to Collision Control at the Quantum Limit

See SYCC for the full program of the symposium.

SYCC 1.1	Thu	11:00–11:30	E415	**The unity of physics: the beauty and power of spectroscopy** — •Paul Julienne
SYCC 1.2	Thu	11:30–12:00	E415	**Using high-resolution molecular spectroscopy to explore how chemical reactions work** — •Johannes Hecker Denschlag
SYCC 1.3	Thu	12:00–12:30	E415	**Monitoring ultracold collisions with laser light** — •Olivier Dulieu
SYCC 1.4	Thu	12:30–13:00	E415	**The birth of a degenerate Fermi gas of molecules** — •Jun Ye

Invited Talks of the joint PhD-Symposium – Many-body Physics in Ultracold Quantum Systems

See SYPD for the full program of the symposium.

SYPD 1.1	Thu	14:30–15:00	E415	**Entanglement and quantum metrology with microcavities** — •Jakob Reichel
SYPD 1.2	Thu	15:00–15:30	E415	**Many-body physics in dipolar quantum gases** — •Francesca Ferlaino
SYPD 1.3	Thu	15:30–16:00	E415	**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — •Markus Greiner
SYPD 1.4	Thu	16:00–16:30	E415	**Quantum gas in a box** — •Zoran Hadzibabic

Invited Talks of the joint Symposium Quantum Optics and Quantum Information with Rigid Rotors

See SYQR for the full program of the symposium.

SYQR 1.1	Fri	11:00–11:30	E415	**Femtosecond timed imaging of rotation and vibration of alkali dimers on the surface of helium nanodroplets** — •Henrik Stapelfeldt
SYQR 1.2	Fri	11:30–12:00	E415	**Quantum toolbox for molecular state spaces** — Eric Kubischta, Shubham Jain, Ian Teixeira, Eric R. Hudson, Wesley C. Campbell, Mikhail Lemeshko, •Victor V. Albert
SYQR 1.3	Fri	12:00–12:30	E415	**Coherent rotational state control of chiral molecules** — •Sandra Eibenberger-Arias
SYQR 1.4	Fri	12:30–13:00	E415	**Optically levitated rotors: potential control and optimal measurement** — •Martin Frimmer
SYQR 2.1	Fri	14:30–15:00	E415	**Rotational optomechanics with levitated nanodumbbells** — •Tongcang Li
SYQR 2.2	Fri	15:00–15:30	E415	**Quantum rotations of nanoparticles** — •Benjamin A. Stickler
SYQR 2.3	Fri	15:30–16:00	E415	**Quantum control of trapped molecular ions** — •Stefan Willitsch
SYQR 2.4	Fri	16:00–16:30	E415	**Full control over randomly oriented quantum rotors: controllability analysis and application to chiral observables** — •Monika Leibscher

Sessions

Q 1.1–1.8	Mon	11:00–13:00	A320	**Quantum Technologies (joint session Q/A/QI)**
Q 2.1–2.7	Mon	11:00–13:00	E001	**Matter Wave Optics**
Q 3.1–3.8	Mon	11:00–13:00	E214	**Quantum Computing and Simulation (joint session Q/QI)**
Q 4.1–4.8	Mon	11:00–13:00	F102	**Cold Molecules (joint session MO/Q)**
Q 5.1–5.8	Mon	11:00–13:00	F342	**Quantum Optics: Open Quantum Systems**

Q 6.1–6.8	Mon	11:00–13:00	F442	**Quantum Effects (QED) (joint session Q/A)**
Q 7.1–7.32	Mon	16:30–19:00	Empore Lichthof	**Poster I**
Q 8.1–8.49	Mon	16:30–19:00	Empore Lichthof	**QI Poster I (joint session QI/Q)**
Q 9.1–9.7	Mon	17:00–19:00	A320	**Quantum Gases: Bosons I**
Q 10.1–10.7	Mon	17:00–19:00	E001	**Photonics I**
Q 11.1–11.8	Mon	17:00–19:00	E214	**Precision Measurements: Gravity I**
Q 12.1–12.6	Mon	17:00–18:45	F107	**Precision Spectroscopy of Atoms and Ions I (joint session A/Q)**
Q 13.1–13.7	Mon	17:00–19:00	F303	**Ultra-cold Atoms, Ions and BEC I (joint session A/Q)**
Q 14.1–14.8	Mon	17:00–19:00	F342	**Quantum Technologies: Color Centers I (joint session Q/A/QI)**
Q 15.1–15.8	Mon	17:00–19:00	F442	**Quantum Communication (joint session Q/QI)**
Q 16.1–16.8	Tue	11:00–13:00	A320	**Photonic Quantum Technologies (joint session Q/QI)**
Q 17.1–17.7	Tue	11:00–13:00	E001	**Integrated Photonics I (joint session Q/QI)**
Q 18.1–18.7	Tue	11:00–13:00	E214	**Quantum Optics: Cavity and Waveguide QED I**
Q 19.1–19.7	Tue	11:00–12:45	F303	**Precision Spectroscopy of Atoms and Ions II (joint session A/Q)**
Q 20.1–20.8	Tue	11:00–13:00	F342	**Quantum Gases: Bosons II**
Q 21.1–21.8	Tue	11:00–13:00	F442	**Quantum Technologies: Color Centers II (joint session Q/QI)**
Q 22.1–22.86	Tue	16:30–19:00	Empore Lichthof	**Poster II**
Q 23.1–23.7	Wed	11:00–12:45	A320	**Optomechanics I & Optovibronics**
Q 24.1–24.6	Wed	11:00–12:45	B305	**Quantum Networks I (joint session QI/Q)**
Q 25.1–25.8	Wed	11:00–13:00	E001	**Solid State Quantum Optics**
Q 26.1–26.8	Wed	11:00–13:00	E214	**Quantum Gases: Bosons III**
Q 27.1–27.7	Wed	11:00–13:00	F303	**Ultra-cold Atoms, Ions and BEC II (joint session A/Q)**
Q 28.1–28.8	Wed	11:00–13:00	F342	**Quantum Technologies: Trapped Ions (joint session Q/QI)**
Q 29.1–29.7	Wed	11:00–13:00	F428	**Implementations: Ions and Atoms (joint session QI/Q)**
Q 30.1–30.8	Wed	11:00–13:00	F442	**Nano-optics**
Q 31.1–31.8	Wed	11:00–13:00	F102	**Precision Measurements: Atom Interferometry I (joint session Q/A)**
Q 32	Wed	13:00–14:00	F342	**Members' Assembly**
Q 33.1–33.8	Wed	14:30–16:30	A320	**Quantum Gases: Bosons IV**
Q 34.1–34.7	Wed	14:30–16:30	B305	**Quantum Communication (joint session QI/Q)**
Q 35.1–35.8	Wed	14:30–16:30	E001	**Quantum Optics: Cavity and Waveguide QED II**
Q 36.1–36.7	Wed	14:30–16:30	E214	**Quantum Technologies (joint session Q/MO/QI)**
Q 37.1–37.7	Wed	14:30–16:15	F142	**Collisions (with Q) (joint session MO/Q)**
Q 38.1–38.8	Wed	14:30–16:30	F303	**Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)**
Q 39.1–39.8	Wed	14:30–16:30	F342	**Quantum Optics & Nano-Optics**
Q 40.1–40.8	Wed	14:30–16:30	F442	**Photonics II**
Q 41.1–41.6	Wed	14:30–16:00	F428	**Ultra-cold Atoms, Ions and BEC III (joint session A/Q)**
Q 42.1–42.36	Wed	16:30–19:00	Empore Lichthof	**Poster III**
Q 43.1–43.65	Wed	16:30–19:00	Empore Lichthof	**QI Poster II (joint session QI/Q)**
Q 44.1–44.8	Wed	17:00–19:00	A320	**Integrated Photonics II (joint session Q/QI)**
Q 45.1–45.8	Thu	11:00–13:00	A320	**Photonics III**
Q 46.1–46.7	Thu	11:00–13:00	B305	**Quantum Control (joint session QI/Q)**
Q 47.1–47.7	Thu	11:00–13:00	E001	**Precision Measurements with Optical Clocks (joint session Q/QI)**
Q 48.1–48.7	Thu	11:00–13:00	E214	**Optomechanics II**
Q 49.1–49.7	Thu	11:00–13:00	F303	**Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)**
Q 50.1–50.8	Thu	11:00–13:00	F342	**Quantum Gases: Fermions I**
Q 51.1–51.8	Thu	14:30–16:30	A320	**Precision Measurements**
Q 52.1–52.7	Thu	14:30–16:30	E001	**Floquet Engineering and Topology**
Q 53.1–53.7	Thu	14:30–16:30	E214	**Single Quantum Emitters (joint session Q/QI)**
Q 54.1–54.8	Thu	14:30–16:30	F102	**Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)**
Q 55.1–55.7	Thu	14:30–16:30	F303	**Precision Spectroscopy of Atoms and Ions III (joint session A/Q)**
Q 56.1–56.8	Thu	14:30–16:30	F342	**Quantum Gases: Fermions II**

Q 57.1–57.8	Thu	14:30–16:30	F428	**Quantum Networks II (joint session QI/Q)**
Q 58.1–58.8	Thu	14:30–16:30	F442	**Quantum Optics with Photons I**
Q 59.1–59.80	Thu	16:30–19:00	Empore Lichthof	**Poster IV**
Q 60.1–60.7	Fri	11:00–12:45	A320	**Photonics IV**
Q 61.1–61.7	Fri	11:00–13:00	E001	**Quantum Optics with Photons II**
Q 62.1–62.8	Fri	11:00–13:00	E214	**Precision Measurements: Gravity II**
Q 63.1–63.6	Fri	11:00–12:45	F107	**Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)**
Q 64.1–64.6	Fri	11:00–12:45	F303	**Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)**
Q 65.1–65.8	Fri	11:00–13:00	F342	**Many-body Physics**
Q 66.1–66.8	Fri	11:00–13:00	F428	**Quantum Metrology (joint session QI/Q)**
Q 67.1–67.8	Fri	11:00–13:00	F442	**Optomechanics III**
Q 68.1–68.7	Fri	14:30–16:15	B305	**Quantum Gases: Bosons V**
Q 69.1–69.7	Fri	14:30–16:30	F303	**Ultra-cold Atoms, Ions and BEC V (joint session A/Q)**
Q 70.1–70.8	Fri	14:30–16:30	F342	**Precision Measurements: Atom Interferometry II (joint session Q/A)**
Q 71.1–71.4	Fri	14:30–15:30	F442	**Quantum Optics: Cavity and Waveguide QED III**
Q 72.1–72.6	Fri	14:30–16:00	B302	**Precision Spectroscopy of Atoms and Ions V (joint session A/Q)**

Members' Assembly of the Quantum Optics and Photonics Division

Wednesday 13:00–14:00 F342

Q 1: Quantum Technologies (joint session Q/A/QI)

Time: Monday 11:00–13:00 Location: A320

Q 1.1 Mon 11:00 A320

Holography with single photons — •Hrvoje Skenderovic and Denis Abramovic — Institute of Physics, Bijenicka cesta 46, 10000 Zagreb, Croatia

Holography relies on interference between two beams, reference and object. Although single photon can not be divided, holograms with heralded single-photon source in a classical holographic setup were recorded, due to indistinguishable paths. The amplitude and phase reconstructions show quantum enhancement for heralded over non-heralded channel. Non-classical nature of heralded photons is verified by continuous measurement of g2(0) of the light source during hologram acquisition.

Q 1.2 Mon 11:15 A320

Three-Dimensional Imaging of Single Atoms in an Optical Lattice via Helical Point-Spread-Function Engineering — •Tangi Legrand[1], Falk-Richard Winkelmann[1], Wolfgang Alt[1], Dieter Meschede[1], Andrea Alberti[1], and Carrie Weidner[2] — [1]Institut für Angewandte Physik, Universität Bonn, Germany — [2]Quantum Engineering Technology Laboratories, H. H. Wills Physics Laboratory and Department of Electrical and Electronic Engineering, University of Bristol, United Kingdom

Quantum gas microscopes can resolve atoms trapped in a 3D optical lattice down to the single site in the horizontal plane. Along the line of sight, however, a much lower resolution is achieved if the position is inferred from the defocus alone, although tomographic methods have been applied to extract this information [1]. However, phase-front engineering can be used to localize emitters in 3D with sub-micrometer resolution from a single experimental image [2]. The technique consists of shaping the imaging system's point spread function (PSF) such that it results in an axially rotating azimuthally asymmetric distribution. By means of a spatial light modulator, we create a double-helix PSF consisting of two lobes whose relative angle encodes an atom's axial position. We demonstrate 3D localization at the level of single lattice sites in a quantum gas microscope. As we show, the technique also features an increased depth of field. This method can find applications in other quantum gas experiments to extend the domain of quantum simulation from 2D to 3D. [1] O. Elíasson *et al.* Phys. Rev. A **102**, 053311 (2020), [2] S.R.P. Pavani *et al.* PNAS **106**, 2995 (2009).

Q 1.3 Mon 11:30 A320

Tomography of distant single Atoms — •Florian Fertig[1,2], Yiru Zhou[1,2], Pooja Malik[1,2], Anastasia Reinl[1,2], Tim van Leent[1,2], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Entanglement of distant quantum memories forms the building block of quantum networks. Neutral atoms with long coherence times are possible candidates for such a quantum network link and can be entangled via the entanglement swapping protocol. Our experiment consists of two nodes, currently 400 m apart, employing single optically trapped Rubidium-87 atoms as quantum memories. A new collection setup allows for an increased entanglement event rate of 1/6 Hz allowing a state analysis and reconstruction of the entangled state.

Here, we use quantum state tomography for the first time on atom-atom entanglement and evaluate the influence of different kind of experimental improvements on the fidelity of the entangled state. We introduce time-filtering, a method to increase the atom-atom entanglement fidelity. At the cost of events we reach a fidelity $> 90\%$ well suited for demanding tasks like device-independent QKD.

Q 1.4 Mon 11:45 A320

Mid-Infrared Quantum Scanning Microscopy with Visible Light — •Josué R. León-Torres[1,2], Jorge Fuenzalida[1], Marta Gilaberte Basset[1], Sebastian Töpfer[1], and Markus Gräfe[1,2,3] — [1]Fraunhofer Institute of Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, D-07745 Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Abbe Center of Photonics, Max-Wien-Platz 1, D-07745 Jena, Germany — [3]Technische Universität Darmstadt, Institute of Applied Physics, Hochschulstraße 6, D-64289 Darmstadt, Germany

Abstract: Laser scanning microscopy (LSM) is known to be the workhorse for modern life-science, it allows to get new insights into a variety of biological processes. LSM together with illumination in the mid infrared region (Mid-IR) permits to map the chemical composition of samples to a space frame. However, low-light observations in the Mid-IR spectrum are still challenging and a limiting factor for a faster development. A label-free quantum imaging system is presented here, capable of performing the detection in the visible regime, while illuminating the sample with undetected light in the Mid-IR region. Our quantum imaging with undetected light implementation aims to retrieve amplitude and phase images of biological samples containing a variety of functional groups that are present in the Mid-IR region. Due to the momentum correlations shared by the entangled photon-pair the illumination can take place in the Mid-IR spectrum and the detection can be carried out with silicon-based technology in the VIS spectrum.

Q 1.5 Mon 12:00 A320

GHz bandwidth four-wave mixing in a thermal rubidium vapor — •Max Mäusezahl[1], Felix Moumtsilis[1], Moritz Seltenreich[1], Jan Reuter[2,3], Hadiseh Alaeian[4], Harald Kübler[1], Matthias Müller[2], Charles Stuart Adams[5], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Forschungszentrum Jülich GmbH, PGI-8, Germany — [3]Universität zu Köln, Germany — [4]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, USA — [5]Department of Physics, Joint Quantum Centre (JQC), Durham University, UK

Fast coherent control of Rydberg excitations is essential for quantum logic gates and on-demand single-photon sources based on the Rydberg blockade as demonstrated for room-temperature rubidium atoms in a micro-cell. During our ongoing development of the next generation of this single-photon source we employ state-of-the-art 1010 nm pulsed fiber amplifiers to drive a Rydberg excitation via the 6P intermediate state.

Here we report on time resolved observations of nanosecond pulsed four-wave mixing and GHz Rabi cycling involving the 32S Rydberg state. Our results show oscillating dynamics of the mixed photons on the final transition of the FWM cycle. The MHz repetition rates and significantly higher photon yields allow us to study and optimize the antibuching through elaborate pulse shaping motivated by numerical simulations. Such excitation timescales also pave the way towards fast optimal control methods for high fidelity Rydberg logic gates.

Q 1.6 Mon 12:15 A320

Absorption sensing mode in radio frequency electrometry using Rydberg atoms in hot vapors — •Matthias Schmidt[1,2], Stephanie Bohaichuk[1], Chang Liu[1], Harald Kübler[2], and James P. Shaffer[1] — [1]Quantum Valley Ideas Laboratories, 485 Wes Graham Way, Waterloo, ON N2L 6R1, Canada — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffendwaldring 57, 70569 Stuttgart

We present theoretical work on atom-based RF E-field sensing using Rydberg atoms in hot vapors. There are two distinct strategies to detect the electric field strength of the RF wave, namely the Autler-Townes limit, where the splitting of the dressed states is proportional to the incident RF electric field strength and the amplitude regime, where we determine the electric field by measuring the difference of transmission in the presence of the RF electromagnetic field. We present theoretical calculations for the amplitude regime, using a two photon excitation scheme, that show how the scattering of the probed transition changes in the presence of the RF electromagnetic field. We find an analytical expression in the thermal limit with finite wave vector mismatch that yields an accurate approximation compared to full density matrix calculation in the strong coupling limit. Our work extends the understanding of the detection of weak RF E-fields with Rydberg-atom based RF sensors.

Q 1.7 Mon 12:30 A320

Light Filtration With Hot Atomic Vapor Cells — •Denis Uhland, Yijun Wang, Helena Dillmann, and Ilja Gerhardt — Institute of Solid State Physics, Light and Matter Group, Leibniz University Hannover

The interaction of light and atoms is one of the cornerstones to study quantum effects. Atomic vapor cells offer a convenient and robust framework to such studies. Not only can fundamental quantum effects be studied, but their robustness and ease of handling is beneficial for a vast array of applications in quantum technology. Examples are magnetometers, electrometers, atomic clocks, or laser frequency stabilization. We probe hot vapor cells with lasers and external magnetic fields to enable spectral narrow filtering and show their potential to improve confocal and wide-field imaging in microscopy [1]. Not only does this method efficiently suppress the undesired laser leakage of scattered excitation light, but it also enhances the detection efficiency by 15% compared to one of the best commercially available long-pass filters. Another flavor of such filters utilizes magnetic fields and founds on the Macaluso-Corbino effect. This allows to enable GHz-wide band-pass filters in a Faraday configuration.

[1] Uhland, D., Rendler, T., Widmann, M. et al. Single molecule DNA detection with an atomic vapor notch filter. EPJ Quantum Technol. 2, 20 (2015). https://doi.org/10.1140/epjqt/s40507-015-0033-1

Q 1.8 Mon 12:45 A320

Optimization and readout-noise analysis of a hot vapor EIT memory on the Cs D1 line — •Luisa Esguerra[1,2], Leon Messner[1,3], Elizabeth Robertson[1,2], Norman Vincenz Ewald[1], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany. — [3]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany.

Efficient, noise-free quantum memories are indispensable components of quantum repeaters, which will be crucial for the realization of a global quantum communication network [1, 2]. We have realized a technologically simple, in principle satellite-suited quantum memory in Cesium vapor, based on electromagnetically induced transparency (EIT) on the ground states of the Cs D1 line [3]. We simultaneously optimize the end-to-end efficiency and the signal-to-noise level in the memory, and have achieved light storage at the single-photon level with end-to-end efficiencies up to 13(2)% at a minimal noise level corresponding to $\bar{\mu}_1 = 0.07(2)$ signal photons. From varying the control laser power at different detunings we gain profound understanding of the physical origin of the readout noise, and thus determine strategies for further minimization.

[1] M. Gündoğan et al., npj Quantum Information 7, 128 (2021)
[2] J. Wallnöfer et al., Commun Phys 5, 169 (2022)
[3] L. Esguerra, et al., arXiv:2203.06151 (2022)

Q 2: Matter Wave Optics

Time: Monday 11:00–13:00 Location: E001

Invited Talk Q 2.1 Mon 11:00 E001

Interferometry with Bose-Einstein Condensates for inertial sensing — •Sven Abend[1], Christian Schubert[2], Matthias Gersemann[1], Ernst M. Rasel[1], and QUANTUS-QGYRO Teams[1] — [1]Institut für Quantenoptik, LU Hannover — [2]DLR-SI, Hannover

Matter-wave interferometers show great a potential for improving inertial sensing. The absence of drifts recommends them for a variety of applications in geodesy, navigation, or fundamental physics. Bose-Einstein condensates (BECs) provide the means to achieve the lowest expansion energies of few picokelvin.

Such ensembles, bring in reach extremely accurate gravimeters, accelerometers and gyroscopes. An atom interferometer with scalable area may be formed in a twin lattice combined with a relaunch mechanism to obtain multi loops as well. Due to this scalability, it offers the perspective of reaching unprecedented sensitivities for rotations in comparably compact sensor head setups.

Moreover, atom-chip technologies offer the possibility to generate a BEC, paving the way for field-deployable miniaturized atomic devices. The extremely low expansion energies of BECs open up to extend the time atoms spend in the interferometer to tens of seconds. This brings in reach unprecedented sensitivities in space-borne applications.

Q 2.2 Mon 11:30 E001

Wave-packet evolution during laser pulses driving an atomic clock transition — •Nadja Augst and Albert Roura — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm

Single-photon optical transitions enable novel applications of atom interferometry to dark-matter and gravitational-wave detection [1–3]. This work investigates the wave-packet evolution for an atom's center of mass during a laser pulse driving such a transition. Particular attention is paid to the effects of finite pulse duration on the central trajectory of the atomic wave packets and the phase that they acquire in the diffraction process. While the resulting deviations of the central trajectories are typically quite small, they can have a significant impact on the interferometric phase shift in high-precision measurements and a detailed analysis is therefore important. Our approach relies on a description of the matter-wave propagation in terms of central trajectories and centered wave packets [4].

[1] Y. A. El-Neaj et al., *EPJ Quantum Technol.* **7**, 6 (2020).
[2] M. Abe et al., *Quantum Sci. Technol.* **6**, 044003 (2021).
[3] L. Badurina et al., *J. Cosmol. Astropart. Phys.* **05** (2020) 011.
[4] A. Roura, *Phys. Rev. X* **10**, 021014 (2020).

Q 2.3 Mon 11:45 E001

Transverse motion of diffraction wavelets in a matter-wave beam-splitter — •Oleksandr Marchukov and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, D-64289, Darmstadt, Germany

Matter-wave interferometry with Bose-Einstein condensates (BECs) is a rapidly developing tool for precision measurements [1]. A crucial element of matter-wave interferometers is a beam-splitter that employs the interaction of atoms with laser beams and creates superposition of macroscopically occupied momentum states.

We consider the Bragg beam-splitting of an off-axis BEC with three-dimensional Gaussian laser beams [2]. The transverse position offset leads to the inseparability of the longitudinal and transverse motion during the pulse. Experimentally, this manifests as transverse momentum kicks. In order to describe both the Bragg oscillations between the momenta components and the motion of the BEC, we model the wavefunction of the condensate via a superposition of squeezed coherent states, initially separated by even multiples of laser photon momentum. We construct a Lagrangian field theory using the variational ansatz [3] that leads to a system of coupled Bragg-Schrödinger equations and Newtonian equations for the Bragg fragments. We compare our results with the (3+1)D numerical simulations, using realistic experimental parameters, and find a good agreement.

[1] D. Becker, et al., Nature 562, 3910395 (2018)
[2] A. Neumann, et al., Phys. Rev. A 103, 043306 (2021)
[3] R. Walser, et al. New J. Phys., 10(4), 045020 (2008)

Q 2.4 Mon 12:00 E001

Four-Wave Mixing Neurons — •Kai Niklas Hansmann and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4a, D-64289 Darmstadt, Germany

Artificial neural networks, and especially deep learning, are a rapidly increasing field and have found numerous applications in research and industry over recent years [1]. We propose to implement such a network in a physical system, utilizing the non-linearity of interacting ultracold quantum gases.

For this, we study the four-wave mixing process in bosonic matter waves [2, 3]. Given a superposition of three waves, the four-wave mixing process generates a fourth signal wave. We identify the three initial waves as input and the signal wave as output of an artificial neuron. We show, that the constructed system fulfills all requirements for neuron activity and responds to the input in a non-linear fashion. We perform benchmark calculations to determine the performance of the neuron.

Considering a homogeneous Bose-Einstein condensate in three dimensions with present plane matter waves, we find Josephson-like oscillations beyond the undepleted pump approximation. These can be expressed analytically and agree with numerical Gross-Pitaevskii simulations.

[1] O. Abiodun et al., *Heliyon* **4**, e00938 (2018).
[2] L. Deng et al., *Nature* **398**, 218-220 (1999).
[3] J.M. Vogels et al., *Phys. Rev. Lett.* **89**, 020401 (2002).

Q 2.5 Mon 12:15 E001

Multipole analysis for matter-wave optics — •Jan Teske and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt, D-64289, Germany

In 1934 Frits Zernike introduced his orthogonal "Kreisflächenpolynome" to describe wavefront aberrations in optics. Nowadays, technical matter-wave optics requires [1] high precision modeling as interferometry with Bose-Einstein condensates [2] is paving the way to a new era of quantum technologies.

In this contribution, we present a (3+1)D multipole expansion adapting Zernike's for a consistent and efficient description for matter-wave optics with BECs. For this purpose, we are characterizing external potentials obtained by magnetic chip traps and Laguerre-Gaussian beams used for trapping, guiding and delta-kick collimation. Afterwards, we demonstrate an efficient approximation scheme for different density distributions. Further, we discuss density and phase perturbations that we analyze in terms of our partial wave expansion. Finally, we discuss phase aberrations caused during delta-kick collimation and the resulting density distortions after long expansion times.

[1] C. Deppner et al., PRL 127 (2021)
[2] M. Lachmann et al., Nature Communications 12, 1317 (2021)

Q 2.6 Mon 12:30 E001

A reflective atom interferometer — •Johannes Fiedler and Bodil Holst — University of Bergen, Bergen, Norway

The field of atom interferometry has expanded enormously over the last few decades. Atom interferometers are used in various applications, from measuring fundamental physics constants to atomic clocks. Detailed planning is ongoing for using atom interferometers as dark matter and gravitational wave detectors. Most applications use cold atoms or BEC and split the wave function via laser pulses. Transmission interferometer with thermal atoms uses dielectric objects [1] or a standing laser field [2] to split the beam. Via these techniques, the matter wave can only be separated over a few mrad [3]. A reflected atom interferometer can dramatically enhance the beam splitting to a rad. In this talk, we will present a scheme for a reflective atom interferometer using the surface diffraction of two parallel plates to achieve the large-angle separation of the wave function [4]. We will show a realisable interferometer setup and demonstrate the expected interference patterns.

[1] N. Gack et al. Phys. Rev. Lett. 125, 050401 (2020). [2] S. Eibenberger et al. Phys. Rev. Lett. 112, 250402 (2014). [3] C. Brand et al. Nature Nanotechnology 10, 845 (2015). [4] J. Fiedler et al. in preparation.

Q 2.7 Mon 12:45 E001

QUANTUS-2: Double Bragg atom interferometry in microgravity on long time scales — •Laura Pätzold[1], Merle Cornelius[1], Dorthe Leopoldt[2], Julia Pahl[3], Anurag Bhadane[4], Waldemar Herr[2,5], Patrick Windpassinger[4], Christian Schubert[5], Markus Krutzik[3,6], Sven Herrmann[1], Ernst M. Rasel[2], and The QUANTUS Team[1,2,3,4,7,8] — [1]U Bremen — [2]LU Hannover — [3]HU Berlin — [4]JGU Mainz — [5]DLR SI — [6]FBH Berlin — [7]U Ulm — [8]TU Darmstadt

Matter wave interferometry allows for quantum sensors with a wide range of applications, e.g. in geodesy or tests of fundamental physics. As a pathfinder for future space missions, QUANTUS-2 is a high-flux Rb-87 Bose-Einstein condensate (BEC) experiment operating in microgravity at the ZARM drop tower in Bremen. By applying a magnetic lens, we are able to reduce the total internal kinetic energy of the BEC to $\frac{3}{2}k_B \cdot 38\,\mathrm{pK}$ in three dimensions [1]. This is required to enhance the atomic signal for interferometry on time scales in the order of seconds as envisioned for future space based precision experiments. Via a retro-reflex interferometry setup, QUANTUS-2 is performing atom interferometry based on double Bragg diffraction in free fall. In this talk, we present our latest results on the performance of open Mach-Zehnder type interferometers on extended time scales.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers DLR 50WM1952-1957.

[1] C. Deppner et al., Phys. Rev. Lett. **127**, 100401 (2021)

Q 3: Quantum Computing and Simulation (joint session Q/QI)

Time: Monday 11:00–13:00 Location: E214

Q 3.1 Mon 11:00 E214

An energy estimation benchmark for quantum computers — •Andreas J C Woitzik[1], Edoardo Carnio[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany

While quantum-mechanical measurements yield intrinsically stochastic outcomes, the fluctuations in the output of current noisy intermediate-scale quantum (NISQ) devices are caused, for the large part, by imperfections in the hardware components and operations. We propose a simple energy estimation benchmark and use it to gauge noise-induced fluctuations in the output of IBM Quantum System One in Ehningen. We find that the errors we measure in our benchmark correlate only weakly with the reported calibration data of the machine. Moreover, a time-resolved analysis of the benchmark measure reveals periodic oscillations and unpredictable outliers that cannot be mildened by measurement error mitigation. We conclude that we cannot rely on single realizations of circuit outcomes, but rather on appropriately sampled ensembles.

Q 3.2 Mon 11:15 E214

Effects of particle losses in two photon quantum walks — •Federico Pegoraro, Philip Held, Sonja Barkhofen, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS) Warburger Str. 100, 33098, Paderborn, Germany

In real photonic quantum systems losses are an unavoidable factor limiting the scalability to many modes and particles, restraining their application in fields as quantum information and communication. A considerable amount of engineering effort has been taken in order to improve the quality of particle sources and system components. At the same time, data analysis and collection methods based on post-selection have been used to mitigate the effect of particle losses. This has allowed for investigating experimentally multi-particle evolutions where the observer lacks knowledge about the system's intermediate propagation states. Nonetheless, the fundamental question how losses affect the behaviour of the surviving subset of a multi-particle system has not been investigated so far. For this reason, with this contribution we study the impact of particle losses in a quantum walk of two photons reconstructing the output probability distributions for one photon conditioned on the loss of the other in a known mode and temporal step of our evolution network. We present the underlying theoretical model that we have devised in order to model controlled particle losses, we describe a platform capable of implementing our theory and in the end we show how localized particle losses change the output distributions without altering their asymptotic spreading properties.

Q 3.3 Mon 11:30 E214

Realization of a photonic ultra-fast free space discrete-time quantum walk. — •Jonas Lammers, Syamsundar De, Nidhin Prasannan, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Recent developments in quantum systems based on time-multiplexed techniques have shown high potential for quantum communication and information processing protocols. The time-multiplexed architecture has already been used in experiments demonstrating exponential increase in GHZ state generation and quantum advantage based on Gaussian boson sampling. Here we demonstrate an ultra-fast free space discrete-time quantum walk. With the newest generation of SNSPDs enabling higher than ever timing resolutions, we were able to overcome the need for long optical delay paths - typically optical fibers - in time-multiplexed systems. The resulting free space architecture enables us to increase measurement repetition rates by multiple orders of magnitude and promises increased stability. Furthermore, we can expect an increase in efficiency which would lead to an exponential increase in observable step numbers. We performed a full polarization resolved quantum walk characterization using coherent light and heralded single photons, observing up to twenty quantum walk steps with high similarity to theory. The demonstrated ultra-fast quantum walk is a promising platform for quantum simulations and opens up a path for large-scale quantum photonic networks utilizing time-multiplexing.

Q 3.4 Mon 11:45 E214

Multiphoton entangled graph states from a single atom — •Philip Thomas, Leonardo Ruscio, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching

Optical photons interact very weakly with their environment, making them robust qubit carriers suitable for numerous protocols in quantum information science. Many experiments on photonic entanglement that were carried out over the last decades relied on the well-established toolbox of non-linear optics. However, the underlying process is intrinsically probabilistic and thus poses a practical limit on the size of entangled states one can generate. In order to avoid this obstacle, we use a single Rubidium atom in an optical cavity as an efficient photon source [1]. Single photons are emitted sequentially while the atomic spin qubit mediates entanglement between them. We show that by tailored single-qubit operations on the atomic state we generate Greenberger-Horne-Zeilinger (GHZ) states of up to 14 photons and linear cluster states of up to 12 photons. A combined source-to-detection efficiency of 43% leads to coincidence rates orders of magnitude higher than the previous state-of-the-art [2]. Our work represents a step towards scalable measurement-based quantum computing and communication.

[1] P. Thomas *et al.*, Nature **608**, 677-681 (2022).
[2] H.-S. Zhong *et al.*, Phys. Rev. Lett. **121**, 250505 (2018).

Q 3.5 Mon 12:00 E214

Multi-photon coherence and interference — •Sholeh Razavian[1,2], Klaus Mølmer[3], Jasmin Meinecke[1,2], and Harald Weinfurter[1,2] — [1]Department fur Physik, Ludwig-Maximilians-Universitat, Munich, Germany — [2]Max-Planck-Institute for quantum optics, Garching, Germany — [3]Niels Bohr Institute, Copenhagen, Denmark

The Hong-Ou-Mandel(HOM) effect is a prime example of photon interference in quantum optics and forms the basis for many quantum applications. While HOM interference is a two-photon effect, we are lifting it to the general case, considering multi-photon interference including decoherence effects.

Here we are analyzing polarized photons propagating in integrated waveguide arrays with polarization dependent coupling. With two observables, one for path and one for polarization. The output is a superposition of all the different configurations in a possibly non-classical state.

We analyze multiphoton coincidence measurements and samples from the probability distribution in order to investigate polarization-dependent decoherence of the total quantum state.

Q 3.6 Mon 12:15 E214

Physical computing with a superfluid — Maurus Hans[1], •Elinor Kath[1], Marius Sparn[1], Nikolas Liebster[1], Felix Draxler[2], Helmut Strobel[1], and Markus Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Germany — [2]Interdisziplinäres Zentrum für Wissenschaftliches Rechnen, Universität Heidelberg, Germany

We report on the implementation of a hybrid neural network with a physical system. As a proof-of-concept we implement the regression and interpolation of a non-linear, one-dimensional function. A digital micromirror device is used to prepare an elongated atomic cloud and encode input values by imprinting a phase profile onto the superfluid. Its non-linear response is detected by the observation of the density distribution, from which the output value is generated by a trained linear layer. We compare the performance of this hybrid neural network for different parameters and give an outlook for further directions.

Q 3.7 Mon 12:30 E214

A novel quantum simulation platform for ultracold ytterbium atoms using hybrid optical potentials — •Etienne Staub[1,2], Tim O. Höhn[1,2], Guillaume Brochier[1,3], Clara Z. Bachorz[1,2,4], David Gröters[1,2], Bharath Hebbe Madhusudhana[1,2,5], Nelson Darkwah Oppong[1,2,6], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]École normale supérieure de Lyon, Lyon, France — [4]Max-Planck-Institut für Quantenoptik, Garching, Germany — [5]Los Alamos National Laboratory, Los Alamos, USA — [6]JILA, University of Colorado at Boulder, Boulder, USA

We report on our recent progress constructing a novel experimental platform for ytterbium atoms. Our approach combines optical lattices and optical tweezers, providing a versatile, robust and scalable environment for both analog and digital quantum simulation. A central ingredient of our implementation are optical potentials at the magic and tune-out wavelengths for the ground and meta-stable clock state of ytterbium. Leveraging high-resolution optical clock spectroscopy, we present preliminary results from our efforts to experimentally determine two new magic wavelengths and the ground-state tune-out wavelength near the narrow cooling transition at 556nm. Furthermore, we demonstrate loading, cooling and imaging of individual atoms in our tweezer array. Possible avenues of research include the simulation of lattice gauge theories and the implementation of quantum computing schemes by means of collisional gates.

Q 3.8 Mon 12:45 E214

Robust localization effects in dipolar systems with positional disorder — •Adrian Braemer and Martin Gärttner — University Heidelberg, Germany

We study a Heisenberg XXZ model with disordered couplings arising from power-law interactions between randomly positioned sites. This type of system is realized naturally in a large range of quantum simulation platforms. We numerically find indications of a localization transition and derive a simple, effective model for the local integrals of motion based on strongly interacting pairs. By systematically taking into account higher order resonances, we find a strong renormalization flow towards a pure Ising model. This might explain the numerically observed robustness of the localization transition, which in this system does not drift towards strong disorder strength as the system size is increased. One may even conjecture that the localized phase could be stable in this type of systems.

Q 4: Cold Molecules (joint session MO/Q)

Time: Monday 11:00–13:00 Location: F102

Q 4.1 Mon 11:00 F102

A Continuous Source of Aluminium Monofluoride Molecules — •Maximilian Doppelbauer[1], Sidney C. Wright[1], Simon Hofsäss[1], José Eduardo Padilla-Castillo[1], Sebastian Kray[1], Russell Thomas[1], Boris Sartakov[1], Stefan Truppe[1,2], and Gerard Meijer[1] — [1]Molecular Physics, Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]Centre for Cold Matter, Blackett Laboratory, Imperial College London, Prince Consort Road, London SW7 2AZ, United Kingdom

The aluminium monofluoride (AlF) molecule is a unique candidate for laser cooling and trapping experiments. As a starting point, we require a high-density molecular source. In our original setup, we can generate AlF by reaction of laser-ablated aluminium atoms with NF_3

in a pulsed cryogenic buffer gas source with more than 10^{12} molecules per steradian per ablation shot. By exploiting the reaction of AlF_3 and Al in a UHV oven above 600°C, we can generate a continuous thermal AlF beam with a total brightness of about 10^{16} molecules per steradian per second.

In this contribution, we present spectroscopic information on vibrational levels up to $v'' = 4$ and rotational levels to above $J'' = 80$ in the $X^1\Sigma^+$ electronic ground state that we obtained using the oven source as well as first experiments laser cooling AlF.

Q 4.2 Mon 11:15 F102

Cryo-cooled beams of "small" macromolecules — •Jingxuan He[1,2,3], Lena Worbs[1,2], Surya Kiran Peravali[1,4], Armando D. Estillore[1], Amit K. Samanta[1,3], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Germany — [3]Center for Ultrafast Imaging, Universität Hamburg, Germany — [4]Fakultät für Maschinenbau, Helmut-Schmidt-Universität,Germany

We have demonstrated the preparation of cold and controlled dense beams of nanoparticles and macromolecules designed for x-ray single-particle diffractive imaging (SPI). We exploit buffer-gas cell cooling and aerodynamic focusing techniques [1-2]. We are extending the cooling and control techniques developed for SPI to experimental investigations of ultrafast electron dynamics in complex biomolecules. We aim at disentangling charge and energy transfer following electronic excitation, which still has important open questions [3].

Here, we present our approach to prepare appropriate samples of cryogenically-cooled proteins to study these also biologically important elemantary processes, for instance, using photofragmentation mass spectrometry and velocity map imaging.

[1]A. K. Samanta, et al., *Structural dynamics* **7** , 024304 (2020)
[2]L. Worbs, et al., *In preparation*, (2022)
[3]H. Duan, et al., *PNAS* **114** , 8493 (2017)

Q 4.3 Mon 11:30 F102

Zeeman slowing of CaF — •Mariia Stepanova, Timo Poll, Paul Kaebert, Supeng Xu, Mirco Siercke, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover

Our Zeeman slowing scheme for laser-cooling of molecules with favorable Franck-Condon factors promises a substantial increase in molecular number in the velocity range of under 20 m/s, which is required for loading a Magneto-Optical Trap (MOT). The scheme stands out in its ability to not only lower the initial mean velocity of the molecular beam, but also to compress the velocity distribution in a continuous fashion. In this talk, we will present our most recent status on the experiment to achieve the goal of slowing and cooling CaF molecules generated from a buffer gas cell source, followed by our efforts to implement a dual-frequency MOT without sub-Doppler heating, discussed in [1].

[1] S. Xu, P. Kaebert, M. Stepanova, T. Poll, M. Siercke and S. Ospelkaus, DOI: https://doi.org/10.1103/PhysRevResearch.4.L042036

Q 4.4 Mon 11:45 F102

Ortho ground state preparation of cooled and trapped formaldehyde molecules — •Maximilian Löw, Martin Ibrügger, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Methods to directly cool polar molecules to ultracold temperatures saw remarkable progress in recent years. One of the most promising techniques in this field is optoelectrical Sisyphus cooling which can provide a large number of electrically trapped molecules at the sub-millikelvin level [1]. However, molecules in their absolute ground state cannot be addressed with this approach.

Cold ground state molecules can still be created by first applying Sisyphus cooling to, e.g., formaldehyde (H_2CO) molecules in the rotational states $|J=3,K_a=3,K_c=0>$ and $|4,3,1>$. Then, we use optical pumping to transfer them via a vibrational transition to their ortho ground state $|1,1,0>$. In a proof-of-principle experiment trapped ground state molecules with a temperature of 65 mK and trapping times of several seconds were obtained. There is no fundamental obstacle to achieving lower temperatures in the future.

As formaldehyde in this state is stable against inelastic two-body collisions this fulfills an important requirement for evaporative or sympathetic cooling of this species in, e.g., a microwave trap which takes one a step closer to the long-term goal of quantum degeneracy.

[1] A. Prehn *et al.*, *Phys. Rev. Lett.* **116**, 063005 (2016).

Q 4.5 Mon 12:00 F102

Towards direct laser cooling of barium monofluoride — •Marian Rockenhäuser, Felix Kogel, Einius Pultinevicius, Tatsam Garg, and Tim Langen — UNI Stuttgart, 5. Physikalisches Insitut, IQST

We report on our progress towards the laser cooling of BaF molecules. This molecular species shows high promise for various types of precision measurement applications. However, due to its high mass, complex hyperfine structure and branching losses through intermediate states, it is also notoriously difficult to cool. In an effort to realize laser cooling, we have performed high-resolution absorption spectroscopy of the lowest rovibrational states to determine an improved set of molecular constants. This has allowed us to identify missing cooling and repumping transitions necessary to realize laser cooling of BaF, as well as to realize near background-free fluorescence imaging of a cold molecular beam

Q 4.6 Mon 12:15 F102

Optical properties of the Si_2O^+ cation — •Emil Mickein, Taarna Studemund, Kai Pollow, Marko Förstel, and Otto Dopfer — Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Germany

The emission of SiO from stars is well-known and proven. Moreover, the existence of different μm-sized silicate grains in interstellar dust is observed, but the formation pathway is unknown and information concerning larger molecules and their ions is missing.
In our project we are looking for transitions of cluster and characterize them via their measured optical spectrum.
In this talk, experimental data and quantum chemical calculations on the absorption and dissociation properties of Si_2O^+ are presented. The spectrum of Si_2O^+, which are created in a laser vaporization source, was obtained by photodissociation of mass-selected Si_2O^+ cations in a tandem mass spectrometer. The experimental results are discussed and compared with theoretical results of TD-DFT calculations.
Significantly, our optical spectrum provides the first spectroscopic information for this simple triatomic cation.

Q 4.7 Mon 12:30 F102

Threshold photodetachment spectroscopic studies of C_2^- — •sruthi purushu melath, christine maria lochmann, markus nötzold, robert wild, and roland wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria

Photodetachment spectroscopy is a powerful spectroscopic technique for determining the internal state distribution of a molecular anion. The dicarbon anion, our current molecule of interest, is a well-studied system due to its stable electronic level structure and potential laser cooling transition [1].

Here we present the photodetachment spectroscopy of C_2^- near threshold in a radiofrequency 16-pole wire trap at 8 K. The main goal of the experiment is to analyze the behavior of the cross section near the threshold, determine the electron affinity more precisely than previously measured [2,3], and if possible, obtain a rotationally resolved photodetachment signal as a function of photon energy. The status of the project will be presented.

[1]. M. Nötzold *et al.,* Phys. Rev. A 106, 023111 (2022) [2]. K. M. Ervin, *et al.,* J. Phys. Chem. 95, 2244 (1991) [3]. B. A. Laws *et al.,* Nat. Commun. 10, 1(2019)

Q 4.8 Mon 12:45 F102

Theoretical study of photoassociation of ultracold $^{23}Na^{39}K$ and ^{39}K — •Baraa Shammout[1], Charbel Karam[2], Leon Karpa[1], Eberhard Tiemann[1], Silke Ospelkaus[1], and Olivier Dulieu[2] — [1]Institut für Quantenoptik, Universität Hannover — [2]Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton

Understanding the physics underlying ultracold alkali atom-diatom collisions is essential for full quantum control on ultracold molecules. The long-range photoassociation (PA) process of loosely-bound ultracold trimers from a scattering state of atom-diatom is a possible pathway to investigate their collisional properties. In this work, we present a long-range model for modeling photoassociation of ultracold $^{23}Na^{39}K$ and ^{39}K close to the molecular resonant excitation $NaK(X^1\Sigma) \rightarrow NaK(b^3\Pi)$. We have calculated potential energy surfaces (PESs) for the low-lying doublet excited states of NaK_2 up to the $NaK(b^3\Pi)+K(4s)$ dissociation limit. We extracted the energy of vibrational-rotational levels using the time-independent close-coupling method, restricted to the long-range PESs. Finally, we demonstrate the possibility of experimental observation of trimer photoassociation by estimating trimer PA-rates.

Q 5: Quantum Optics: Open Quantum Systems

Time: Monday 11:00–13:00 Location: F342

Q 5.1 Mon 11:00 F342

Certifying multi-mode light-matter interactions in lossy resonators — •Dominik Lentrodt[1,2], Oliver Diekmann[2], Christoph H. Keitel[2], Stefan Rotter[3], and Jörg Evers[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [3]Institute for Theoretical Physics, Vienna University of Technology (TU Wien), 1040 Vienna, Austria

Few-mode models - such as the Jaynes-Cummings model and its generalisations - have been an indispensable tool in studying the quantum dynamics of light-matter interactions in optical resonators. Recently, however, novel regimes featuring strong coupling in combination with large losses have attracted attention in various experimental platforms. In this context, central assumptions of these canonical quantum optical models have to be revisited. In this talk, we will discuss recent extensions of Jaynes-Cummings type few-mode models and an associated class of loss-induced multi-mode effects. In particular, we will introduce an exact basis transformation to derive few-mode theory from first principles and a simple classification criterion for the appearance of multi-mode effects in lossy resonators. We will further discuss open problems, the relation to alternative approaches, and implications for recent experiments in x-ray cavity QED with Mössbauer nuclei — an emerging platform at the high-energy frontier of quantum optics, featuring lossy resonators doped with ultra-low decoherence emitters.

Q 5.2 Mon 11:15 F342

Noise-induced networks — •Frederic Folz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

We analyze a transport problem on a graph with multiple constraints and in the presence of noise and determine the network topologies to which the dynamics converges. The dynamics results from the interplay of a nonlinear interaction function and Gaussian, additive noise. The deterministic model is based on an optimization algorithm that has been designed starting from biologically-inspired models and reproduces essential elements of a neural network. The amplitude of the noise is a variable that simulates the temperature of an external bath. We show that different network topologies emerge as a function of the noise amplitude and are generally multi-stable. Remarkably, the system converges to the most robust configuration at finite noise amplitudes thereby exhibiting a resonant-like behavior. Interestingly, this configuration is not found by the deterministic dynamics and is reached with the maximal convergence. Our results suggest that stochastic dynamics can boost transport on a nonlinear network.

Q 5.3 Mon 11:30 F342

Loss-induced topological protection — •Vinzenz Zimmermann[1], Konrad Tschernig[2], Kurt Busch[1,3], and Armando Perez-Leija[2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Berlin, Germany — [2]CREOL/College of Optics, University of Central Florida, Orlando, Florida, USA — [3]Max-Born-Institut, Berlin, Germany

Arrays of evanescently coupled waveguides have become a veritable platform with especially promising prospects in topologically protected photonics [1]. By employing topologically protected states in specifically engineered arrays of waveguides, precise manipulations and robust propagation of classical and quantum states of light can be realized in entirely passive systems [2]. These topological effects have been shown to exist beyond Hermitian quantum-optical systems [3]. We explore the possibility to synthesize topologically protected steady states in dissipative waveguide arrays realizing non-Hermitian effective Hamiltonians. The Su-Schrieffer-Heeger (SSH) model implementing one dimensional dimer chains is studied in the framework of the tight binding model [4]. From an open quantum system perspective, the existence of zero modes in the spectrum of the corresponding Liouville superoperator is considered. The efficiency of the procedure regarding different initial excitations and system parameters is discussed.

[1] Laser Photonics Reviews 9, 363-384 (2015)
[2] Optica 3, 925 (2016)
[3] Phys. Rev. Research 2, 013387 (2020)
[4] Phys. Rev. Lett. 42, 1698 (1979)

Q 5.4 Mon 11:45 F342

Laser operation based on Floquet-assisted superradiance — •Lukas Broers[1] and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany.

We demonstrate the feasibility of utilizing the non-equilibrium Floquet-assisted superradiant phase (FSP) in the dissipative Rabi-Dicke model for laser operation. We relate this phase to the population inversion of Floquet states of the driven two-level systems in the cavity. This inversion is depleted near Floquet energies that are resonant with the cavity frequency to sustain a coherent light-field. We show the robustness of this state against key imperfections. We consider the effect of a finite linewidth of the driving field and find that the linewidth of the light field in the cavity narrows drastically across the FSP transition, reminiscent of a line narrowing at the laser transition. We find that the FSP is robust against inhomogeneous broadening and that the depleted population inversion of near-resonant Floquet states leads to hole burning in the inhomogeneously broadened Floquet spectra. Finally, the FSP is robust against dissipation processes, with coefficients up to values that are experimentally available.

[1] L. Broers et al., Floquet engineering of non-equilibrium superradiance, arXiv:2203.07434 (2022)
[2] L. Broers et al., Laser operation based on Floquet-assisted superradiance, arXiv:2211.01320 (2022)

Q 5.5 Mon 12:00 F342

Exact treatment of strongly damped quantum dynamics with a continuous degree of freedom — •Stefanie Eileen Bränzel — Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany

Current experiments show an increasing need for an exact description of the system dynamics because of its strong interaction with an environment. For instance in the field of optomechanics, there are many setups where a quantum system couples to an oscillating cantilever, e.g. gravimetry or an optical cavity with an oscillating mirror. However, for such systems the analytical solutions are generally infeasible. Thus, numerical methods are needed.

We apply the Hierarchy of Pure States (HOPS) formalism to strongly-damped open quantum systems with a continuous degree of freedom. This approach provides a non-perturbative description for the interaction between a quantum particle trapped in an arbitrary position-dependent potential with an environment. As an example, we demonstrate the accuracy of this HOPS method written in position space for a harmonic potential where the analytical solution is known for a Lorentzian environment. We furthermore visualize the stochastic dynamics by means of the Wigner representation. We recognize that our approach yields accurate results and plan on applying it to systems with an anharmonic potential, e.g. the Morse potential. We are convinced that the HOPS formalism will allow us to thoroughly investigate optomechanical systems, strongly damped cantilever and much more.

Q 5.6 Mon 12:15 F342

Nested Open Quantum Systems description of Photonic Bose–Einstein Condensate in a Planar Cavity — •Andris Erglis[1] and Stefan Yoshi Buhmann[2] — [1]University of Freiburg, Germany — [2]University of Kassel, Germany

The photonic Bose–Einstein Condensate (BEC) is a macroscopic state of light forming in thermal equilibrium with a sharply peaked ground mode occupation. A prevalent way to achieve it is through a photon-dye interaction in a cavity with high-reflectance mirrors.

Here we present a rigorous derivation of the dynamics of a photon BEC employing a nested open quantum systems approach [1]. We describe dye molecules using the polaron Hamiltonian and model photon–molecule interactions using macroscopic quantum electrodynamics. We obtain rates of the condensation process via Green's tensor, allowing us to describe the photon BEC in arbitrary geometries.

We apply our formalism to a simple geometry – a finite-size planar cavity. Through numerical simulations, we demonstrate that condensation occurs in a two-dimensional untrapped gas, where each cavity mode is characterised by the transverse wave vector of the photons. We analytically study the behaviour of the photonic BEC in the limit of the size of the mirrors becoming very large or the mode spacing going to zero.

[1] "Nested Open Quantum Systems Approach to Photonic Bose–Einstein Condensation", Andris Erglis and Stefan Yoshi Buhmann, arXiv:2203.11039 (2022).

Q 5.7 Mon 12:30 F342

Quantum Master Equations for finite system-bath coupling — •Tobias Becker[1], Lingna Wu[1], Alexander Schnell[1], Juzar Thingna[2] und André Eckardt[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany — [2]Department of Physics and Applied Physics, University of Massachusetts, Lowell, MA 01854, USA

For open quantum systems that are coupled to their environment an effective description for the reduced dynamics of the system is of great interest. For ultraweak coupling between system and bath Lindblad master equations yield an adequate approximation. However for finite coupling or for non-Markovian dynamics approaches beyond Lindblad are required. A good candidate is the Redfield equation, which is obtained in second order of the system bath coupling. However it is well known to violate positivity in certain parameter regimes. To overcome this problem we derive an alternative Lindbladian approximation to the Redfield equation, which is valid beyond the ultraweak coupling regime. Moreover we propose yet another quantum master equation, which corrects Redfield by drawing inspiration from the statistical mean-force Gibbs state.

Q 5.8 Mon 12:45 F342

Superradiance in 1D chains of multilvel atoms — •Aleksei V. Konovalov, Tom Schmit, and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

We analyse the properties of the light coherently scattered by a periodic array of atoms when the distance between neighbouring atoms is comparable with the wavelength. We specifically focus on superradiant scattering and analyse it as a function of the array periodicity. We also account for the multilevel atomic structure, where several dipole transitions of the same atom couple to the incident light and can mutually interfere. Starting from the full quantum master equation [1], we determine the properties of the light by means of the coherent-dipole approximation [2]. We then determine the collective Lamb-shift for chains of Na^{23} and Rb^{87} atoms in experimentally relevant geometries.

[1] Aleksei Konovalov and Giovanna Morigi. "Master equation for multilevel interference in a superradiant medium." In: *Physical Review A* 102.1 (2020), p. 013724.
[2] Bihui Zhu, John Cooper, Jun Ye, and Ana Maria Rey. "Light scattering from dense cold atomic media." In: *Physical Review A* 94.2 (2016), p. 023612.

Q 6: Quantum Effects (QED) (joint session Q/A)

Time: Monday 11:00–13:00 Location: F442

Q 6.1 Mon 11:00 F442

In the eye of the beholder: Interference in multi-atom dynamics — •Stefan Yoshi Buhmann[1] and Janine Franz[1,2] — [1]University of Kassel, Germany — [2]University of Freiburg, Germany

The Casimir–Polder force between an excited with a ground-state atom had been subject to an old controversy: Does its distance dependence exhibit oscillations due to interference [1] or not [2]? A time-dependent analysis of this scenario has revealed that the correct answer is a matter of perspective: the force on the excited atom does oscillate while that on the ground-state atom does not [3].

We complete this picture by studying the rate with which the excitation of the atom gets lost or is transferred to the ground-state atom, considering a range of channels: environment-assisted spontaneous decay, resonance energy transfer, and Auger decay. Again, we find that the correct answer depends on the perspective and hence the specific process considered.

[1] L. Gomberoff, R. R. McLone, and E. A. Power, J. Chem. Phys. **44**, 4148 (1966).
[2] E. A. Power and T. Thirunamachandran, Phys. Rev. A **47**, 2539 (1993).
[3] P. Barcellona, R. Passante, L. Rizzuto, and S. Y. Buhmann, Phys. Rev. A **94**, 012705 (2016).

Q 6.2 Mon 11:15 F442

Quantum friction near nonreciprocal media and chiral media — •Omar Jesús Franca Santiago and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, Germany

We investigate how the quantum friction experienced by a polarisable charged particle moving with constant velocity parallel to a planar interface is modified when the latter consists of a chiral media or nonreciprocal media, with special focus on topological insulators. We use macroscopic quantum electrodynamics to obtain the Casimir-Polder frequency shift and decay rate. These results are a generalization of the respective quantities to matter with time-reversal symmetry breaking which violates the Lorentz reciprocity principle. We illustrate our findings by examining the nonretarded and retarded limits for five examples: a perfectly conducting mirror, a perfectly reflecting nonreciprocal mirror, a three-dimensional topological insulator, a perfectly reflecting chiral mirror and an isotropic chiral medium.

[1] Stefan Yoshi Buhmann, David T. Butcher and Stefan Scheel. New Journal of Physics 14, 083034 (2012).
[2] Sebastian Fuchs, J. A. Crosse and Stefan Yoshi Buhmann. Phys. Rev. A 95, 023805 (2017).
[3] David T. Butcher, Stefan Y. Buhmann, Stefan Scheel, New Journal of Physics 14, 113013 (2012).

Q 6.3 Mon 11:30 F442

Casimir free energy of two bi-isotropic spheres in the plane-wave approach — •Tanja Schoger[1], Benjamin Spreng[2], Gert-Ludwig Ingold[1], and Paulo A. Maia Neto[3] — [1]Universität Augsburg, Augsburg, Germany — [2]University of California, Davis, USA — [3]Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

The Casimir interaction between two bi-isotropic spheres, where polarization mixing upon reflection at each sphere occurs, is studied in the plane-wave approach. We demonstrate that an asymptotic expansion of the Casimir force for large spheres, compared to the surface-to-surface distance, leads to the proximity force approximation (PFA) of the Casimir interaction [1].

A special case of bi-isotropic spheres are perfect electromagnetic conductors (PEMC) interpolating between the spheres with infinite permittivity and infinite permeability for which we present results for vanishing as well as non-zero temperatures [1, 2]. Apart from the PFA results, we also determine the leading PFA corrections and the results for large distances which reveal that the transition from an attractive force to a repulsive force depends on the temperature and the distance between the spheres.

[1] T. Schoger, B. Spreng, G.-L. Ingold, P. A. Maia Neto, Int. J. of Mod. Phys. A 37, 2241009 (2022)
[2] S. Rode, R. Bennett, S. Y. Buhmann, New J. Phys. 20, 043024 (2018)

Q 6.4 Mon 11:45 F442

Heat transport using nonreciprocal media — •Nico Strauss, Stefan Yoshi Buhmann, and Omar Jesús Franca Santiago — Institute of Physics, University of Kassel, Germany

The second law of thermodynamics dictates that heat flows from warm to cold objects, thereby providing a direction of time [1]. In the optics of nonreciprocal media [2], an arrow of time is alternatively provided by the observation that optical paths cannot be reversed. How are these two notions compatible of the level of quantum electrodynamics? In order to answer this question, we calculate the nanoscale heat transfer between the surfaces of two nonreciprocal media, namely axionic topological insulators which exhibit a temperature difference $\Delta T = T_1 - T_2$. We investigate the impact of the nonreciprocal properties of the plates on the heat transfer and investigate their interplay with the second law in the near field.

[1] Volokitin, A. I.; Persson, B. N. J. Rev. Mod. Phys. **4**, 79 (2007)
[2] S. Y. Buhmann et al., New J. Phys. **14**, 083034 (2012).

Q 6.5 Mon 12:00 F442

The Casimir-Polder force near an elliptical nanowire — •Bettina Beverungen[1], Kurt Busch[1,2], and Francesco Intravaia[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, Max-Born-Str. 2 A, 12489 Berlin, Germany

Quantum and thermal fluctations of the electromagnetic field lead to many highly interesting and nontrivial effects such as the emergence of forces between neutral objects. These persist even in the limit of zero temperature due to the irreducible nature of the quantum fluctuations. While these interactions typically fall off rapidly with distance, they play a significant role at short separations relevant for modern nanotechnological applications. It is therefore important to understand how they depend on the geometry and material properties of the objects involved.

A prominent example is the Casimir-Polder force, which describes the interaction between a neutral atom or nanoparticle and a macroscopic object. Here, we investigate this interaction for an atom near a metallic nanowire of elliptical cross section. To verify the validity of our results, we show that they reduce to the case of a circular nanowire for low ellipticities. As a way to gain additional insight into the problem, we analyze the asymptotic behavior of the interaction energy with a particular focus on the distance regime where the effect of curvature is most pronounced.

Q 6.6 Mon 12:15 F442

Constraints on Beyond-Standard-Model Particles from the Muon's Anomalous Magnetic Moment — •Clive Reese and Stefan Yoshi Buhmann — University of Kassel, Germany

While the Standard Model is incredibly successful in predicting the anomalous magnetic moment of the electron, the same theory fails at predicting the anomalous magnetic moment of the muon a_μ. Recent experimental results by Fermilab reinforce the discrepancy, displaying a deviation of $4.2\,\sigma$ [1]. Particles Beyond Standard Model (BSM) can contribute to a_μ due to one-loop corrections and thus explain the anomaly.

In our work we assume one fermion and one (pseudo-)scalar particle in the interaction, where either one of the particles or both can be BSM particles. We calculate the contribution to a_μ in dependence of the masses, coupling constants and electric charges. Considering experimental and theoretical limits it turns out that chiral couplings constitute good candidates, while uncharged fermions like neutrinos cannot explain the anomaly. A scalar in PeV-Scale is too heavy to be detected, but an theoretically explain the anomaly.

[1] B. Abi et al.: 'Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm', Phys. Rev. Lett. **126**, 141801 (2021)

Q 6.7 Mon 12:30 F442

Influence of quantum vacuum fluctuations on the causality of field correlations within nonlinear crystals — •Cristofero Oglialoro[1], Frieder Lindel[2], Fabian Spallek[1], and Stefan Yoshi Buhmann[1] — [1]University of Kassel, Germany — [2]University of Freiburg, Germany

A major consequence of Heisenberg's uncertainty principle is that, even though the expectation value of a quantum field vanishes, its ground state exhibits so-called quantum vacuum fluctuations. In recent years, experimental progress has made it possible to study the ground state fluctuations through electro-optic sampling by measuring changes in the polarisation of a laser pulse passing through a nonlinear crystal. The rotation of the polarisation can be attributed to the interaction of the pulse with the quantum vacuum. Macroscopic QED allows to describe the changes in this vacuum structure induced by the interaction with dielectric macroscopic bodies and provides a theoretical framework to survey its physical signatures. Studies of the correlation of the field of two laser pulses in a nonlinear crystal have even shown that points causally disconnected according to special relativity can exhibit a nonvanishing correlation function due to the interaction with the vacuum fluctuations [1]. We want to further investigate the influence of the quantum vacuum on the causality of correlations within dielectric macroscopic bodies and the possibility to explore the space-time structure of vacuum correlations in the altered metric provided by a nonlinear crystal in analogy to the behaviour in curved space-time.

[1] F. F. Settembrini, et al., Nat. Commun. 13, 3383 (2022).

Q 6.8 Mon 12:45 F442

Dispersive and dissipative dielectrics with 'scalar-field' type environments — •Sascha Lang[1,2,3], Stefan Yoshi Buhmann[1], Ralf Schützhold[2,4,3], and William G. Unruh[5,6] — [1]University of Kassel, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Universität Duisburg-Essen, Germany — [4]Technische Universität Dresden, Germany — [5]University of British Columbia, Canada — [6]Texas A&M University, United States

Macroscopic quantum electrodynamics provides a powerful framework for studying a large variety of dispersive and dissipative media [1]. To account for quantum fluctuations, a noise polarisation is manually incorporated into the formalism. This phenomenological approach is inspired by microscopic derivations (based on, e.g., the famous Huttner-Barnett model [2]) which explicitly describe damping via interactions with baths of harmonic oscillators. Unfortunately, models with harmonic-bath type environments are usually quite involved and facilitate straightforward solutions only for time independent systems and in the case of relatively simple position dependences.

We present an alternative approach and model dissipation via a scalar field that may carry energy and information away from the medium [3,4]. This model is much simpler than established microscopic descriptions and still holds for explicitly time-dependent systems.

[1] Scheel & Buhmann, Acta Phys. Slov. **58**, 675 (2008)
[2] Huttner & Barnett, PRA **46**, 4306 (1992)
[3] Lang, Schützhold & Unruh, PRD **102**, 125020 (2020)
[4] Lang, Sauerbrey, Schützhold & Unruh, PRR **4**, 033074 (2022)

Q 7: Poster I

Time: Monday 16:30–19:00 Location: Empore Lichthof

Q 7.1 Mon 16:30 Empore Lichthof

Power scaling of an Yb-doped diode-pumped mode-locked laser — •Thomas Konrad[1], Andy Steinmann[1], Tobias Steinle[1], Monika Ubl[1], Matthias Seibold[2], Gabriele Untereiner[3], Mario Hentschel[1], Philipp Flad[1], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]IHFG, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [3]1st Physics Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Today's high power solid-state lasers are often constructed as thin-disk lasers. They require complex and expensive pumping systems. An easier and cheaper way is using solid-state lasers with conventional bulk crystals. They cannot reach the power levels of thin-disk lasers, but can still provide sufficient peak power for many applications such as nonlinear frequency conversion, yet being cheaper than disk lasers. In this work we follow different approaches to increase the average power of a femtosecond mode-locked Yb:KGW laser with a dual crystal cavity design. One important aspect is improving the crystal cooling to overcome thermal limitations. This can be realized by soldering the crystal to the heat sink to improve the thermal contact. Other aspects include optimizing crystal dimensions, doping concentrations, as well as pump and mode sizes.

Q 7.2 Mon 16:30 Empore Lichthof

5 W high power femtosecond laser at 2060 nm from a stabilized doubly resonant optical parametric oscillator — •han rao[1,2], Christian markus dietrich[1,2], José ricardo cardoso de andrade[3], robin mevert[1,2], fridolin jakob geesmann[1], ayhan demicran[1,2], ihar babushkin[1,2,3], and uwe morgner[1,2] — [1]Leibniz University Hannover, Institute of Quantum Optics, Hannover, Germany — [2]Cluster of Excellence PhoenixD, Hannover, Germany — [3]Max Born Institute, Berlin, Germany

A high power 2 μm femtosecond laser source is demonstrated by a degenerate doubly resonant optical parametric oscillator (DROPO), which is synchronously-pumped by a home-built Yb:YAG Kerr-lens mode-locked thin-disk laser, emitting pulses at wavelength of 1030 nm with a pulse duration of 270 fs, 25 W output power and 32.5 MHz repetition rate. By using a dither-free scheme which utilizes a "parasitic" sum-frequency generation (SFG) of the signal and pump intracavity as error signal, we stabilize our degenerate DROPO. A stable output power of 4.9 W at degeneracy is observed with a pump power of 18.7 W, which results in a conversion efficiency of 26%. The long-term stability measurement of the power over 40 minutes showed a root mean square (RMS) power noise of 1.1%.

Q 7.3 Mon 16:30 Empore Lichthof

Towards generation of high power 2 μm pulses in the few cycle regime — •Jon Morten Drees[1], David Zuber[1,2], Ihar Babushkin[1,2,3], and Uwe Morgner[1,2,4] — [1]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Disciplines) 30167 Hannover, Germany — [3]Max Born Institute, Max-Born-Straße 2a, 10117 Berlin, Germany — [4]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany

Ultrashort pulses in the short-wavelength infrared (SWIR) can be used for various applications such as high harmonic generation or an all-optical Attoclock. Most of the systems that provide such radiation are built with laser materials based on thulium or Cr:ZnSe. While such Systems can achieve high output powers they usually have relatively long pulse durations and require additional pulse compression to reach the few cycle regime. Due to this disadvantage we wanted to go another way to create 2 μm radiation. A regenerative amplifier, providing 750 μJ pulses at 1030 nm with a repetition rate of 100 kHz, is used to generate white-light at 700 nm, which is amplified in a non-collinear optical parametric amplifier (NOPA). By difference frequency generation with the 1030 nm pump a 2 μm seed can be generated efficiently. With two additional NOPA stages the SWIR pulse can then be amplified to achieve high pulse energies. This approach will allow us to achieve pulse durations of approximately 20 fs with pulse energies of up to 100 μJ.

Q 7.4 Mon 16:30 Empore Lichthof

Compression of Laser Pulses by Nonlinear Multipass Cells — •Peer Biesterfeld[1], David Zuber[1,2], Jose Mapa[1], and Uwe Morgner[1,2,3] — [1]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Disciplines) 30167 Hannover, Germany — [3]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany

Due to the high efficiency, good scalability to high pulse energies and compactness multipass cells (MPCs) for post compression of laser pulses, are currently of high interest. In particular, gas-filled MPCs enable the compression of pulses with high pulse energies and simultaneously high average powers with efficiencies higher than 90%.

The compression of picosecond pulses to the few cycle regime is beyond the limits of a single MPC. To find the best way simulations based on the unidirectional pulse propagation equation (UPPE) in cylindrical coordinates are performed, leading to a two stage setup. In the first cell, a high compression ratio is achieved in order to exploit the high reflectivity of broadband dielectric mirrors. The high compression factor is achieved by using molecular gases as a nonlinear medium at comparatively low gas pressure and low cost. Gires-Tournois Interferometers (GTIs) are being used to compress the pulse before the second cell, which is operated in an atomic noble gas using silver mirrors.

To verify the functionality of the cell, the spectral, temporal and spatial characteristics of the output are measured and compared with the simulation results.

Q 7.5 Mon 16:30 Empore Lichthof

Low order harmonic generation in laser induced borosilicate glass plasma and CdTe quantum dots — •Victor Kärcher[1], Tobias Reika[1], Pedro F. G. M. da Costa[2], Andrea S.S. de Camargo[2], and Helmut Zacharias[1] — [1]Center for Soft Nanoscience, Busso-Peus Str. 10, 48149 Münster — [2]Sao Carlos Institute of Physics, University of Sao Paulo, Brazil

An investigation of the size dependent influence of CdTe quantum dots on the generation of low order harmonics up to the fifth order in laser induced plasma (LIP) of borosilicate glass for a fundamental wavelength of $\lambda=1030$\,nm and a pulse duration of $\tau=40$\,fs is presented. The aqueous soluble CdTe quantum dots are generated by seed-mediated growth approach. The CdTe nano particles are spin coated with different thicknesses on the surface. Laser intensities above ionization threshold are used to generate the plasma by laser induced optical breakdown. Electrons are accelerated in the electric field emitting harmonics after subsequent recombination. The resulting third harmonic is characterized by blue shifts originating from Raman and phonon lines of the targets. Applying CdTe quantum dots on the targets surface spectral shaping with different sizes and different coating thicknesses is observed. Peak amplification factors between 10 an 17 for small and large particles respectively are reached for the third harmonic while no size dependency of the power density is observed. The fifth harmonic is unaffected by Raman and phonon lines and no spectral shaping is observed as for the third. Amplification factors between 25 and 20 for small and large particle sizes respectively are observed.

Q 7.6 Mon 16:30 Empore Lichthof

Light-field control of electrons in graphene heterojunctions — •Tobias Boolakee[1], Christian Heide[1], Antonio Garzón-Ramírez[2], Heiko B. Weber[1], Ignacio Franco[2,3], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Department of Chemistry, University of Rochester, Rochester, New York, USA — [3]Department of Physics, University of Rochester, Rochester, New York, USA

Ultrashort and intense laser pulses enable the observation and control of electronic processes in a wide variety of systems ranging from atomic and molecular processes to the microscopic motion of electrons inside solids. The time scale of this motion is set by the oscillation period of light, i.e., a few femtoseconds, and thus limits a potential bandwidth of emerging electric currents up to the petahertz range. Here we discuss strong-field physics in graphene, an electric conductor, and therefore, an ideal platform to drive and probe currents induced by the shape of the laser electric field. We can distinguish and take advantage of two types of charge carriers: Real carriers, persisting after their excitation, and virtual carriers, existing during the light-matter interaction only. We show that in a gold-graphene-gold heterostructure, the two types of carriers can be disentangled in their photocurrent response, as they are susceptible to the carrier-envelope phase of incident few-cycle laser pulses. These insights now enable us to design and demonstrate a proof-of-concept of an ultrafast logic gate.

Q 7.7 Mon 16:30 Empore Lichthof

Design and construction of a multi-hit-capable electron spectrometer for ultrafast photoemission experiments — •Jonathan Pölloth, Jonas Heimerl, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen.

The investigation of electron photoemission from metallic needle tips by femtosecond laser pulses allows to gain insights into ultrafast light-matter interaction processes. An important observable is the energy spectrum of the emitted electrons. Two typical features of such strong field spectra are the multiphoton peaks and the plateau due to rescattering. So far, mostly one-electron spectra have been considered, only recently first experiments on multi-electron emission were realised [1,2]. The energy-resolved simultaneous detection of more than one electron from one laser pulse is challenging. Here, we demonstrate a multi-hit-capable electron spectrometer for measuring electron energy spectra emitted from a tungsten needle tip. We use an electrostatic cylindrical deflector analyser that provides spatial separation of different electron energies. The spectrometer is designed and optimized using a commercial finite element solver. Our simulations show that an energy resolution below 0.25 eV at a central electron energy of 100 eV is feasible. This resolution not only allows us to observe strong field effects in the spectrum, but also to distinguish between different multiphoton order peaks.

[1] S. Meier, J. Heimerl and P. Hommelhoff, arXiv:2209.11806 (2022)
[2] R. Haindl et al., arXiv:2209.12300, (2022)

Q 7.8 Mon 16:30 Empore Lichthof

Guided acceleration in dielectric laser accelerators — •Leon

Brückner, Tomás Chlouba, Johannes Illmer, Stefanie Kraus, Julian Litzel, Roy Shiloh, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Dielectric laser accelerators (DLA) are a highly promising technology that could enable the miniaturiziation of accelerators to tabletop or even microchip size. A DLA consists of a silicon nanostructure that is illuminated with a pulsed laser. This creates an evanescent near-field that accelerates electrons entering the channel of the structure. To reach high energies, it is necessary to extend this interaction from micrometer length to millimeters or more. This is challenging as the electrons also experience deflecting forces and are eventually lost. To counteract this, we have employed an alternating phase focusing scheme: the electrons experience alternating transversal focusing and defocusing forces, guiding them through the structure. We could guide a 28.4 keV electron beam through the 225 nm wide channel of a 77 μm long nanostructure [1]. To accelerate with this scheme, it is also necessary to continuously change the grating periodicity (tapering) to conserve phase-matching between the particles and the accelerating field. We have developed and fabricated structures with lengths of several hundred micrometers that combine particle guiding with tapering. These structures will enable acceleration over much longer distances than previously possible. We will report the current state of the experiment. [1] R. Shiloh et al., Nature 597, 498-502 (2021)

Q 7.9 Mon 16:30 Empore Lichthof

Selective intracavity control of interlaced femtosecond soliton combs — •Julia A. Lang[1], Luca Nimmesgern[1], Sarah R. Hutter[2], Alfred Leitenstorfer[2], and Georg Herink[1] — [1]Universität Bayreuth, Deutschland — [2]Universität Konstanz, Deutschland

Complex sequences of multiple solitons are observed in almost all ultrafast mode-locked laser, but their dynamics remain difficult to access, control, or eventually apply. In this contribution, we present deterministic control of relative soliton motion between two interlaced harmonic mode-locked frequency combs. We implement intra-cavity control by acousto-optic modulation allowing us to selectively address pulses in a 40 MHz Er:fiber laser. The soliton trajectories following the external stimulus are rapid, tuneable and deterministic. As shown in [1], intracavity feedback plays an important role in the formation of stable soliton molecules. In this work, we experimentally resolve and analyse the dynamics in the frame of soliton interaction with an effective binding potential. As a proof-of-concept, we demonstrate first steps towards the use of tuneable intracavity soliton motions for ultrafast pump-probe spectroscopy.

[1] Nimmesgern, Luca et al. Soliton molecules in femtosecond fiber lasers: universal binding mechanism and direct electronic control. Optica 8, 10 (2021).

Q 7.10 Mon 16:30 Empore Lichthof

Bi-chromatic current excitation in 2D-materials with complex laser fields — •Simon Wittigschlager[1], Tobias Boolakee[1], Christian Heide[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen (FAU), Erlangen-Nürnberg, Germany — [2]Stanford PULSE Institute, SLAC National Accelerator Laboratory, Menlo Park, California, USA

We present a highly versatile and stable scheme to drive ultrafast light field-induced currents in solids using bi-chromatic laser fields (1550 nm and 775 nm) with full control over the polarisation states of both colours to form complex sum fields. We use these laser fields to steer electrons inside 2D-materials on trajectories, tailored to probe specific characteristics of their underlying band structure. In particular, if the field waveform is asymmetric with respect to time inversion, a momentum imbalance of excited electrons may occur, resulting in a measurable photocurrent. Importantly, while such schemes are usually realized as a Michelson interferometer with both colours separated spatially, our collinear approach grants superior stability with 2.99 mrad long-term phase jitter without the use of active stabilization techniques. We expect this highly stable setup to form the basis for probing electronic phenomena in solids, such as spin polarisation, Berry curvature and topological states, with unprecedented resolution at ultrafast timescales.

Q 7.11 Mon 16:30 Empore Lichthof

Pseudo Thermal Light Source in the XUV for Diffraction Imaging — •Jonas Musall[1], Chris Sträche[1], Philip Mosel[1], Sven Fröhlich[1], David Theidel[2], Hamed Merdji[2], Uwe Morgner[1], and Milutin Kovacev[1] — [1]Institute of Quantum Optics, Cluster of Excellecnce PhoenixD and Quantum Frontiers, Leibniz University Hanover, Welfengarten 1, 30167 Hanover, Germany — [2]LOA, ENSTA ParisTech, CNRS, Ecole Polytechnique, UMR 7639, 828 Boulevard des Maréchaux, 91120 Palaiseau, France

Coherent diffraction imaging (CDI) is a widely-used approach for nanoscale imaging. Besides its frequent use at synchrotron facilities, developments in laser-driven high harmonic sources have made it available on a smaller scale. A less explored possibility is the use of incoherent radiation for diffraction imaging as presented just recently [1]. This would allow a large number of compact sources in the X-ray range to be used for diffraction imaging. We are developing a method to control the degree of coherence in harmonics at 13 nm to investigate the transfer from coherent to incoherent imaging. To achieve this, the harmonic beam is scattered on different densities and sizes of nanoparticles. Additionally, the generated incoherent light can yield useful information on the initial coherent light source, such as the spot size and temporal pulse width [2].

[1] Classen, Anton et al. in: Physical Review Letters 119 (2017), Issue 5 [2] Tamasaku, Kenji et al. in: Journal of Synchrotron Radiation 26 (2019), No. 6

Q 7.12 Mon 16:30 Empore Lichthof

Potential Hazards and Mitigation of X-Ray Radiation Generated by Laser-Induced Plasma from Research-Grade Laser Systems — •Philip Mosel[1], Sven Fröhlich[1], Jose Mapa[1], Sven Kleinert[1], David Zuber[1], Jan Düsing[2], Thomas Püster[2], Günther Dittmar[3], Uwe Morgner[1], and Milutin Kovacev[1] — [1]Institute of Quantum Optics, Cluster of Excellence PhoenixD and Quantum Frontiers, Leibniz Universität Hannover, Hannover, 30167 — [2]Laser Zentrum Hannover e.V., Hannover, 30419 — [3]Ingenieur-Büro Prof. Dr.-Ing. G. Dittmar, Aalen, 73433

Ultra-short pulses and high laser intensities are used in a variety of laser-matter applications in laboratories and industry. Such processes can lead to unwanted generation of X-rays, which are a dangerous radiation factor [1]. We present an analysis of the radiation dose rate and the emitted X-ray spectrum during ablation of a rotating copper cylinder as a function of different laser parameters [2]. Furthermore, we studied the X-ray emission from commonly used metals, alloys and ceramics for ultrafast laser processing [3]. The results show that focused sub-picosecond pulses with intensity higher than 10^{13} W/cm^2 can exceed the annual irradiation limit even in one hour, making adequate shielding a necessity for researchers' safety.

[1] Legall, Herbert, et al., Applied Physics A 125.8 (2019): 1-8.
[2] Mosel, Philip, et al., Optics Express 30.20 (2022): 37038-37050.
[3] Mosel, Philip, et al., Materials 14.16 (2021): 4397.

Q 7.13 Mon 16:30 Empore Lichthof

Coherent imaging using a high-harmonic source — •Chris Sträche, Jonas Musall, Philip Mosel, Sven Fröhlich, Uwe Morgner, and Milutin Kovacev — Leibniz Universität Hannover, Deutschland, Welfengarten 1, 30167 Hanover

With increasingly smaller structures in the semiconductor industry and biological samples in the nanometer range imaging is becoming a challenging task. According to recently published results a resolution around 16 nm can be achieved using coherent diffraction imaging (CDI) [1]. To enhance the resolution limit higher photon energies, scanning the sample with a well-defined beam and overlapping probe positions (Ptychography) can be used. Here we present diffraction imaging using 13 nm based on high-harmonic generation in a semiinfinite gas cell. A variety of samples ranging from basic resolution targets up to biological samples and electronic circuits are to be characterized. With this setup a resolution below 50 nm is expected to be achieved. Keywords: lensless imaging, high-harmonic generation, coherent diffraction imaging, Pytchography Quellen: [1] Eschen, Wilhelm, et al. "Material-specific high-resolution table-top extreme ultraviolet microscopy." Light: Science & Applications 11.1 (2022): 1-10.

Q 7.14 Mon 16:30 Empore Lichthof

Pulse Characterization by Frequency-Resolved Optical Gating (FROG) for Extreme-Ultraviolet (XUV) Frequency Comb Generation — •Fiona Sieber[1], Lennart Guth[1], Jan-Hendrik Oelmann[1], Tobias Heldt[1], Simon Angstenberger[1], Stepan Kokh[1], Janko Nauta[1,2], Nick Lackmann[1], Nele

Griesbach[1], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut for Nuclear Physics, Heidelberg, Germany — [2]Department of Physics, Swansea University, Singleton Park, SA2, United Kingdom

The characterization of femtosecond pulses, which play a major role in precision spectroscopy, is challenging due to the lack of an accurate time reference on the ultrafast scale. Therefore the pulse has to be referenced by itself. In the scope of transferring a near-infrared frequency comb with 100 MHz repetition rate to the XUV-regime via high harmonic generation (HHG), 80 W femtosecond pulses are characterized in the time and frequency domain before the HHG stage using a FROG set-up. [1] The pulse is overlapped with a delayed copy of itself in a nonlinear crystal and the generated second harmonic is detected by a Czerny-Turner spectrometer. The shape, duration and power spectral density of the laser pulse are retrieved from the recorded FROG traces (intensities dependent of frequency and delay) using a noise removal protocol and the ePIE algorithm [2].

[1] J. Nauta et al., Optics Express, Vol. 29, No. 2, 2624 (2018)
[2] P. Sidorenko et al., Optica, Vol. 3, No. 12, 1320 (2016)

Q 7.15 Mon 16:30 Empore Lichthof

A hard X-Ray Split-and-Delay Unit for the HED Instrument at the European XFEL — •Dennis Eckermann[1], Sebastian Roling[1], Matthias Rollnik[1], Peter Gawlitza[2], Karen Appel[3], Liuba Samoylova[3], Harald Sinn[3], Frank Siewert[4], Thomas Tschentscher[3], Frank Wahlert[1], Ulf Zastrau[3] und Helmut Zacharias[1] — [1]Westfälische Wilhelms Universität, Münster, Deutschland — [2]Frauenhofer Institut IWS, Dresden, Deutschland — [3]European XFEL GmbH, Hamburg, Deutschland — [4]HZB, Berlin, Deutschland

A concept of a Split-and-Delay Unit which is capable of doing hard X-Ray pump-probe Experiments.

Q 7.16 Mon 16:30 Empore Lichthof

Simulations of magnetic field amplification and electric field suppression in ultrashort optical laser pulses — •Lorenz Grünewald[1,2], Rodrigo Martín-Hernández[3], Elizaveta Gangrskaia[4], Valentina Shumakova[4], Carlos Hernández-García[3], and Sebastian Mai[1] — [1]Institute for Theoretical Chemistry, Faculty of Chemistry, University of Vienna, Währinger Str. 17, 1090 Vienna, Austria — [2]Vienna Doctoral School in Chemistry (DoSChem), University of Vienna, Währinger Str. 42, 1090 Vienna, Austria — [3]Grupo de Investigación en Aplicaciones del Láser y Fotónica (ALF-USAL), Dpt. Fisica Aplicada, Universidad de Salamanca, Pl. La Merced sn., E37008 Salamanca, Spain — [4]Institute for Photonics, Faculty of Electrical Engineering and Information Technology, TU Wien, Gußhausstr. 27-29, 1040 Vienna, Austria

We present particle-in-cell simulations of the electromagnetic fields of an ultrashort azimuthally polarized laser beam (APB), and demonstrate that they exhibit a region close to the beam axis with strong oscillating magnetic field and vanishing electric field. Upon focusing the APB on a small metal iris, a so-called aperture, fast oscillating ring currents are induced around the aperture circumference, which in turn generates an additional magnetic field (MF) contribution that strongly increases the MF strength at the beam center [3]. Improved experimental setups with different aperture geometries, which yield further enhancements, are suggested, enabling a MF-only spectroscopy. [1] DOI: 10.1016/j.ccr.2015.02.015, [2] DOI: 10.1364/JOSAB.32.000345, [3] DOI: 10.1021/acsphotonics.8b01312

Q 7.17 Mon 16:30 Empore Lichthof

Transportable Laser System Employing Fourier Limited Picosecond Pulses for Laser Cooling of Relativistic Ion Beams — •Benedikt Langfeld[1,2], Sebastian Klammes[3], and Thomas Walther[1,2] — [1]Technische Universität Darmstadt — [2]HFHF Darmstadt — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH

Laser cooling of relativistic ion beams has been shown to be a promising technique to generate cold ion beams with a small velocity distribution. To strongly reduce intrabeam scattering, a well-known problematic effect for high-intensity ion beams which broadens the velocity distribution, pulsed laser systems with broad bandwidths can be employed.

In this work, we present our tunable high repetition rate UV laser system. We have developed a transportable master-oscillator-power-amplifier system, supplying Fourier transform limited pulses with a continuously adjustable pulse length between 50 and 735 ps and repetition rate of 1 to 10 MHz. With two SHG stages, the desired wavelength of 257 nm with up to 4 W average power can be achieved. The combination of the tunable seed laser (3 nm @ IR seed wavelength) and the large Doppler shift allows to easily match the output wavelength to the cooling transition of the ions.

Q 7.18 Mon 16:30 Empore Lichthof

Coherent beam recombination of intense femtosecond beams/pulses after controllable beam break-up and spectral broadening by using optical vortex lattices — •Lyubomir Stoyanov[1,2], Alexander Dreischuh[2], and Gerhard Paulus[1,3] — [1]Institute of Optics and Quantum Electronics, Friedrich Schiller University, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Department of Quantum Electronics, Faculty of Physics, Sofia University, 5 J. Bourchier Blvd., 1164 Sofia, Bulgaria — [3]Helmholtz Institute Jena, Helmholtzweg 4, 07743 Jena, Germany

Ultra-short laser pulse generation, as well as extreme nonlinear processes like high-harmonic generation, are extensively studied and still actively developing fields of modern photonics. Ever since their discovery, researchers are dealing with problems like spectral broadening, filamentation, pulse/beam diagnostics, pulse amplification, and coherent beam recombination. On the other hand, singular optics is another rapidly developing field in which subject of interest is the sculpting of a laser beam by nesting phase singularities in it.

At high beam/pulse intensities, the beams are prone to instabilities, which could be suppressed by controllable splitting of the beam into sub-beams. This makes sense only if there is a reliable way to coherently recombine the sub-beams after their spectral broadening for pulse compression prior entering the laser-matter interaction zone. Some novel approaches towards these unsolved problems in nonlinear optics, based on previous studies on laser beams carrying phase singularities, will be presented and discussed.

Q 7.19 Mon 16:30 Empore Lichthof

Higher-order mean-field theory of chiral waveguide QED — •Kasper Jan Kusmierek[1], Sahand Mahmoodian[1,2], Martin Cordier[3], Jakob Hinney[4], Arno Rauschenbeutel[3,4], Max Schemmer[3], Philipp Schneeweiss[3,4], Jürgen Volz[3,4], and Klemens Hammerer[1] — [1]Institut für theoretische Phyisk, Leiniz University Hannover, Hannover, Germany — [2]Centre for Engineered Quantum Systems, School of Physics, University of Sydney, Sydney, Australia — [3]Departement of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [4]Vienna Center for QuantumScience and Technology, Vienna, Austria

Waveguide QED with cold atoms provides a potent platform for the study of non-equi-librium, many-body, and open-system quantum dynamics. Here we apply an improved mean-field theory based on higher-order cumulant expansions to describe the experimentally relevant, but theoretically elusive, regime of weak coupling and strong driving of large ensembles. We determine the transmitted power, squeezing spectra and the degree of second-order coherence, and systematically check the convergence of the results by comparing expansions that truncate cumulants of few-particle correlations at increasing order. This reveals the important role of many-body and long-range correlations between atoms in steady state. Our approach allows to quantify the trade-off between anti-bunching and output power in previously inaccessible parameter regimes. Calculated squeezing spectra show good agreement with measured data, as we present here.

Q 7.20 Mon 16:30 Empore Lichthof

Collective radiative effects in nanofiber-coupled atomic ensembles: From timed Dicke states to full inversion — •Christian Liedl, Felix Tebbenjohanns, Constanze Bach, Sebastian Pucher, Arno Rauschenbeutel, and Philipp Schneeweiss — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Dicke superradiance is a hallmark effect in quantum optics. There, an ensemble of initially excited atoms can emit a burst of light due to spontaneous phase locking of the atomic dipoles during their decay. In order to observe this phenomenon, the atoms are typically placed in close vicinity of each other. In contrast, here, we study superradiance using macroscopically separated atoms. Each atom is almost unidirectionally coupled to the nanofiber-guided mode, allowing us to describe the dynamics using a cascaded interaction model. In our experiment, we coherently invert up to 1000 atoms and study their decay dynamics. We analyze the role of coherent forward scattering over the whole parameter regime, from weak excitation to almost full inversion. We observe superradiant burst dynamics and find a characteristic threshold behavior. Finally, we find that the superradiant burst has a random phase with respect to the excitation laser. This confirms that the build-up of coherence during the decay indeed stems from spontaneous phase locking of the atoms, which lies at the heart of superradiant.

Q 7.21 Mon 16:30 Empore Lichthof

Ultrafast excitation exchange in multimode cavities — •Oliver Diekmann, Dmitry O. Krimer, and Stefan Rotter — Institute for Theoretical Physics, Vienna University of Technology (TU Wien), Vienna A-1040, Austria

The single-mode Jaynes-Cummings model has been of paramount importance in the development of quantum optics. Recently, also the strong coupling to more than a single mode of an electromagnetic resonator has drawn considerable interest. We investigate how this *superstrong* coupling regime can be harnessed to coherently control quantum systems. In particular, we show that elliptical cavities and Maxwell-Fish-Eye lenses can be used to implement a pulsed excitation-exchange between two quantum emitters. This periodic exchange is mediated by single photon pulses and can be extended to a photon-exchange between two atomic ensembles, for which the coupling strength is enhanced collectively. Our study illustrates how ideas from classical optics can be used in the realm of multimode strong coupling for applications in quantum technology.

Q 7.22 Mon 16:30 Empore Lichthof

Properties of few level atomic systems possessing a permanent dipole moment. — •Alexandra Mirzac — Insitute of Applied Physics, Academiei str.5, MD-2028, Chisinau, Moldova

The quantum optical properties of two- and three-level atomic systems interacting with electromagnetic field is an area of research directed to solve applied problems emerging in laser science, fluorescent spectroscopy, nano-imaging and quantum information theory.

Dipolar two-level atomic systems are widely researched to detect novel multiphoton features and terahertz emission properties. Three level atomic systems with permanent dipole moment include both the properties of a two- and three- level system simultaneously. One can switch between these properties as function of tunable Rabi frequency. Also, three-level system exhibit many coherent interference effects, which can serve as application for testing quantum protocols and information storage. For this reason, few level atomic dipolar systems are perspective setups for generation of tunable electromagnetic waves such as terahertz domain. Consequently, detection of effective terahertz radiation is an emerging task both for applied and theoretical quantum optics. Additionally, non-resonant multiphoton conversion from optical to microwave region is a feasible quantum technology, where few level dipolar systems can be used for solution development.

Thus, the permanent non-zero dipole moment improves the quantum optical properties of few level atomic system in comparison to the similar ones yet in the absence of the permanent dipole moment.

Q 7.23 Mon 16:30 Empore Lichthof

Cavity-enhanced spectroscopy of molecular quantum emitters — •Evgenij Vasilenko, Weizhe Li, Senthil Kuppusamy, Mario Ruben, and David Hunger — Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology (KIT)

Rare earth ions in solid-state hosts are a promising candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. Recently, also rare earth ion-based molecular complexes have shown excellent optical coherence properties [1]. Due to the long optical lifetime of the optical transition $^5D_0$-$^7F_0$, an efficient spin-photon interface for quantum information processing requires the coupling of single ions to a microcavity. Open-access Fabry-Pérot fiber cavities have been demonstrated to achieve high quality factors and low mode volumes, while simultaneously offering large tunability and efficient collection of the cavity mode [2]. Since the used molecular quantum emitters require a cryogenic environment, the demands on mechanical stability of the cavity setup have a high priority. To tackle these challenges, we report on the development of a monolithic type of cavity assembly, sacrificing some lateral scanning ability for the purpose of significantly increasing the passive stability. We integrate molecules into the cavity in the form of a crystalline thin film on a macroscopic mirror and identify a sub-nanometer local surface roughness, sufficient to avoid excessive scattering loss. We report on first studies of cavity-enhanced emission spectroscopy.

[1] Serrano et al., Nature, 603, 241-246 (2022)
[2] Hunger et al., New J. Phys 12, 065038 (2010)

Q 7.24 Mon 16:30 Empore Lichthof

Spectral Theory of Non-Markovian Dissipative Phase Transitions — •Baptiste Debecker, John Martin, and Francois Damanet — Universite de Liege, Liege, Belgique

The generation of phase transitions in quantum systems by coupling to engineered reservoirs provides a powerful way of accessing otherwise inaccessible non-equilibrium properties. However, until now, the theory of dissipative phase transitions (DPTs) has only been well established for quantum systems coupled to idealised Markovian environments, where Liouvillian gap closing is a hallmark. Here we extend the well-known Markovian formalism to general non-Markovian quantum systems. Furthermore, we illustrate our approach by showing how it can be used to reveal DPTs in standard quantum optical models, where the Lindblad description fails to capture them.

Our theory paves the way for exploring the dissipative control of phase transitions beyond the limiting Markovian regime, which is particularly important for understanding real materials or various other experimental platforms such as in the solid state, cold atoms, or cavity and circuit QED.

Q 7.25 Mon 16:30 Empore Lichthof

Optical Microcavity with Coupled Single SiV$^-$ Centers in a Nanodiamond for a Quantum Repeater Platform — •Selene Sachero[1], Robert Berghaus[1], Gregor Bayer[1], Andrea B Filipovski[1], Lukas Antoniuk[1], Niklas Lettner[1], Richard Waltrich[1], Marco Klotz[1], Patrick Maier[1], and Viatcheslav Agafonov[2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Tours University, France

A quantum repeater node requires a long-lived memory that can be addressed coherently. Additionally, efficient writing and reading of quantum states with high rates are crucial. optical cavities can be used as spin-photon platforms to accomplish such requirements. By coupling silicon vacancy defect centers (SiV$^-$) in a nanodiamond to an open Fabry-Pérot cavity, our work paves the way for a light-matter interface with efficient coherent control. Our fully tunable cavity formed by two Bragg mirrors allows short cavity lengths down to $\approx 1\mu$m, and provides efficient coupling of the quantum emitter at liquid helium temperatures.

Here, we perform photoluminescence measurements of SiV$^-$ centers and power-dependent photoluminescence excitation of single SiV$^-$ centers by collecting the cavity modulated sideband. We observe spectrally stable emitters and measure a linewidth close to the Fourier limit below $\Delta\nu = 200$ MHz. With the Purcell-enhanced cavity signal we demonstrate coherent optical driving and access the electron spin all-optical in a strong external magnetic field.

Q 7.26 Mon 16:30 Empore Lichthof

Enhanced photon emission from hBN defects centers inside a tunable fiber-cavity — •Florian Feuchtmayr[1], Gregor Bayer[1], Stefan Häussler[1,2], Richard Waltrich[1], Noah Mendelson[3], Chi Li[3], David Hunger[4], Igor Aharonovich[3,5], and Alexander Kubanek[1,2] — [1]Inst. f. Quantenoptik, Uni Ulm, D — [2]Center f. Integ. Q. Science and Techn. (IQst), D — [3]School of Math./ Phys. Sciences, Univ. of Tech. Sydney, AUS — [4]Phys. Institut, Karlsruhe Inst. of Tech., D — [5]ARC Centre of Exc. f. Transf. Meta-Optical Systems, Univ. of Tech. Sydney, AUS

Coupling single quantum emitters to the mode of optical resonators is essential for the realization of quantum photonic devices. We present a hybrid system consisting of defect centers in a few-layer hexagonal boron nitride (hBN) sheet and a fiber-based Fabry-Pérot cavity. The smooth surface of the chemical vapor deposition grown hBN layers enables efficient integration into the cavity. This hybrid platform is operated over a broad spectral range of more than 30 nm. Owing to cavity funneling, large cavity-assisted signal enhancement up to 50-fold and strongly narrowed linewidths are demonstrated, a record for hBN-cavity systems. On top, we implement an excitation and readout scheme for resonant excitation, allowing to establish cavity-assisted photoluminescence excitation spectroscopy. In total, we reach a milestone for the deployment of 2D materials to fiber-based cavities in practical quantum technologies.

Q 7.27 Mon 16:30 Empore Lichthof

Onset of atomic selforganization in optical cavities: from quantum to thermal momentum distributions — •Tarek Moussa, Simon B. Jäger, Imke Schneider, and Sebastian Eg-

GERT — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, D-67663, Kaiserslautern, Germany

We theoretically study the dynamics of transversally driven atoms coupled to a single-mode optical cavity. The atoms spontaneously form a structured pattern above a critical driving strength. This pattern formation is known as atomic selforganization and results in a Bragg grating of the atoms which supports constructive interference of scattered laser photons. We study this threshold using a mean-field treatment and as a function of the initial temperature of the atomic cloud. Below threshold, we analyze the response of the atomic gas which we find to be fundamentally different in the low and high temperature regimes. For thermal energies much lower than the photon recoil energy we find long-lived coherent oscillations. Instead, for thermal energies well above the recoil energy we find that all fluctuations are strongly damped. Using this insight, we explore the importance of thermal fluctuations regarding resonant parametric amplification realized by a time-periodic modulation of the driving strength.

Q 7.28 Mon 16:30 Empore Lichthof

Coupling and dissipation in a system of Yb atoms interacting with a cavity on a narrow line — •DMITRIY SHOLOKHOV, SARAN SHAJU, KE LI, and JÜRGEN ESCHNER — University of Saarland, Saarbrücken, Germany

^{174}Yb atoms are trapped in a MOT, using the 182 kHz narrow $^1S_0$ - $^3P_1$ (556 nm) transition, residing inside a high-finesse cavity (length 5 cm, finesse 45 000). The trap light also acts as side-pump creating strong atom-cavity interaction. We present a comprehensive investigation of the cavity output spectra for variable trap/pump light detuning, cavity detuning, and atom number. We compare the properties of the cavity light with free-space scattered light (fluorescence) in order to identify the coupling mechanisms and dissipation channels of the coupled system.

Q 7.29 Mon 16:30 Empore Lichthof

Collective atom-cavity coupling and non-linear dynamics with atoms with multilevel ground states — •ELMER SUAREZ[1], FEDERICO CAROLLO[2], IGOR LESANOVSKY[2,3], BEATRIZ OLMOS[2,3], PHILIPPE W. COURTEILLE[4], and SEBASTIAN SLAMA[1] — [1]Center for Quantum Science and Physikalisches Institut, Eberhard-Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [3]3School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [4]Instituto de Física de São Carlos, Centro de pesquisa em óptica é fotônica, Universidade de São Paulo, Brazil

We investigate experimentally and theoretically the collective coupling between atoms with multilevel ground state manifolds and an optical cavity mode. The ensuing dynamics can be conveniently described by means of an effective dynamical atom-cavity coupling strength that depends on the occupation of the individual states and their coupling strengths with the cavity mode. This leads to a dynamical backaction of the atomic populations on the atom-cavity coupling strength. Our results show that the multilevel structure of electronic ground states can significantly alter the relaxation behavior in atom-cavity settings as compared to ensembles of two-level atoms.

Q 7.30 Mon 16:30 Empore Lichthof

Quantum entanglement of atoms in presence of dipole-dipole interaction — •SERGIU BAZGAN, NICOLAE ENAKI, and TATIANA PASLARI — Institute of Applied Physics, State University of Moldova, Chisinau, Moldova, Republic of

It is studied the interaction between the single-mode cavity field and the pair of indistinguishable two-level atoms. The proposed model takes into account the dipole-dipole interaction between two-level atoms. In good cavity limits, the analytical solution for the Schrodinger equation, in the presence of detuning between the cavity field and the atomic transition was obtained. With the help of this solution, the quantum-statistical properties of the system are investigated. Much attention is devoted to the entanglement between atoms. The influence of dipole-dipole interaction and detuning on the resonance on the formation of entanglement is investigated.

Q 7.31 Mon 16:30 Empore Lichthof

Bath Induced synchronization — •SAYAN ROY and GIOVANNA MORIGI — Universität des Saarlandes

Synchronization is a collective phenomenon observed in nature at various scales[1]. An important question is what are the basic ingredients leading to synchronization in the microscopic domain[2,3]. In this work, we analyze the dynamics of two qubits coupled to a chain of linear oscillators acting as a reservoir. This model is amenable to an analytical treatment, which allows us to identify the conditions when the interaction with the phononic bath induces self-sustained oscillations of the two qubits. We then discuss when these dynamics can be understood as quantum synchronization.

[1]. A. Pikovsky, M. Rosenblum, and J. Kurths, Synchronization: A Universal Concept in Nonlinear Sciences (Cambridge University Press, Cambridge, 2001).

[2]. B. Buča, J. Tindall, and D. Jaksch, Nat Commun 10, 1730 (2019).

[3]. B. Bellomo, G. L. Giorgi, G. M. Palma, and R. Zambrini, Phys. Rev. A 95, 043807 (2017).

Q 7.32 Mon 16:30 Empore Lichthof

Network self-organization: the role of the activation function — •FREDERIC FOLZ[1], KURT MEHLHORN[2], and GIOVANNA MORIGI[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

The interplay of nonlinear dynamics and noise is at the basis of coherent phenomena, such as stochastic resonance, synchronization, and noise-induced phase transitions. In a recent work we analysed network dynamics in the presence of Gaussian noise when the activation function, governing the dynamics of the network connections, is a sigmoidal (Hill) function. In these settings we demonstrated the onset of network topologies that maximize the transport efficiency and behave as noise-induced resonances. In this work we systematically analyse this behavior for different classes of activation functions. We identify the activation function that yields the most robust network configuration at the the maximal convergence speed. We then discuss possible applications to neural networks in the quantum domain.

Q 8: QI Poster I (joint session QI/Q)

Time: Monday 16:30–19:00 Location: Empore Lichthof

Q 8.1 Mon 16:30 Empore Lichthof

Towards multi-photon tests of hyper-complex quantum mechanics — •ECE IPEK SARUHAN, MARC-OLIVER PLEINERT, and JOACHIM VON ZANTHIER — Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany

Axioms of quantum mechanics do not tell much about the structure of the Hilbert space such as, e.g., the number system, which could be real, complex, or hyper-complex. Probabilities are amplitude squares of wave functions, which are defined on a complex space in general. Can one consider the result of a dot product to be a hyper-complex number? Asher Peres proposed a way to test hyper-complex quantum mechanics with a single particle scattered from 3 different scatterers [1]. We adapt this test to a 3-slit interference setup and extend it to multi-slit and multi-particle scenarios. We construct Peres-like functions to see if the multitude of paths and particles show different sensitivity to, still hypothetical, hyper-complex phases.

[1] A. Peres, Phys. Rev. Lett. 42, 683 (1979).

Q 8.2 Mon 16:30 Empore Lichthof

An analysis on the almost quantum correlation set — •VITOR SENA and RAFAEL RABELO — University of Campinas, Brazil

A good way to investigate the foundations of quantum theory is through the correlations it allows between results of measurements performed on spatially separated systems. These correlations may present some known nonclassical phenomena such as Bell nonlocality, but, interestingly, the set of nonlocal correlations allowed by quantum theory is quite specific and, in some sense, limited. There is a set of correlations slightly larger than this, known as the almost quantum correlations set, which presents similarities and differences with the set of quantum correlations. In this work, we study the relationship between these sets by numerically estimating their relative volumes in different scenarios. In doing so, we seek to understand the kind of correlations allowed by each one and how their differences can be shown quantitatively.

Q 8.3 Mon 16:30 Empore Lichthof

Reducing Bias in Quantum State Tomography — •Yien Liang[1,2] and Matthias Kleinmann[1] — [1]Universität Siegen, Walter-Flex-Straße 3, D-57068 Siegen, Germany — [2]Peking University, Beijing 100871, China

Quantum state tomography aims to estimate the quantum state of a system using quantum measurements. It is well known that such an estimate cannot be perfect, that is, the procedure may yield an operator with negative eigenvalues or the mean reconstructed state deviates from true state. This is the dilemma of having a nonphysical reconstruction or a biased estimator. It also has been shown that any unbiased estimator has to yield rather large negative eigenvalues. We ask the complementary question: What is the minimum bias of an estimator, even if one is willing to accept an increased variance of the estimator? We show that the bias can indeed be improved by orders of magnitude, but at the price of being rather pathological. We furthermore discuss the behavior of estimators with low bias compared to canonical estimators for large sample sizes and many qubits.

Q 8.4 Mon 16:30 Empore Lichthof

Witnessing non-Markovianity in quantum Brownian motion by quasi-probability distributions in phase-space — •Irene Ada Picatoste Fernández[1], Moritz Ferdinand Richter[1], and Heinz-Peter Breuer[1,2] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

The theory of open quantum systems aims to describe the dynamics of a quantum system coupled to an environment using a limited number of degrees of freedom. The Caldeira-Leggett model of quantum Brownian motion represents a physically interesting example of such systems showing strong memory effects, i.e., non-Markovian dynamics, in certain parameter regimes. Recently, a witness for non-Markovianity has been developed which is based on the Kolmogorov distance between quasi-probability distributions of two states [1]. Additionally, for Gaussian dynamics, a new measure of non-Markovianity can be defined using exclusively the Glauber-Sudarshan P-function. Here, we apply this witness to the Caldeira-Leggett model and show the behaviour of the non-Markovianity measure in different scenarios, while studying where the witness works best.

[1] M. F. Richter, R. Wiedenmann and H.-P. Breuer, arXiv:2210.06058 [quant-ph].

Q 8.5 Mon 16:30 Empore Lichthof

Photon-number resolved model for multimode quantum optical setups based on Gaussian states — •Florian Niederschuh, Erik Fitzke, and Thomas Walther — Institute for Applied Physics, TU Darmstadt, Darmstadt, Germany

Experiments in quantum optics and photonic quantum information protocols regularly employ multimode states with low photon numbers. While early setups used single photon avalanche diodes, recent advances aim at the realization of photon-number resolving detectors. Consequently, mathematical models for the prediction of photon-number resolved detection probabilities may provide valuable insight and aid in experimental design. Here, a formalism for simulating the photon statistics of Gaussian states is presented. It is based on the construction of suitable generating functions, which are further processed by software for automatic differentiation. This allows the extraction of various statistical quantities, e.g. the photon number distribution, cumulative probabilities and statistical moments. The model considers an array of experimental imperfections and agrees with recent measurement results of an entanglement-based phase-time coding setup for quantum key distribution [Fitzke et al. (2022). PRX Quantum, 3, 020341].

Q 8.6 Mon 16:30 Empore Lichthof

Entanglement classification schemes : comparison between Majorana representation and algebraic geometry approaches — •Tom Weelen[1], Naïm Zénaïdi[2], Pierre Mathonet[2], and Thierry Bastin[1] — [1]Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, BE-4000 Liège, Belgium — [2]Département de Mathématique, Université de Liège, BE-4000 Liège, Belgium

Quantum entanglement can be of different kinds [1] and classifying the quantum states in this respect may represent a difficult challenge in general multipartite systems. In particular, entanglement classes that are inequivalent under stochastic local operations and classical communication (SLOCC) are of fundamental importance. For N-qubit systems with $N > 3$, there is an infinity of such SLOCC entanglement classes [1] and it makes sense to gather them into a finite number of families, as was done for symmetric states in Refs. [2,3] using two distinct approaches (Majorana representation and algebraic geometry tools, respectively). Here, we compare these two structures and identify whether they can be embedded into one another or not. To do so, we formulate the structure of Ref. [2] in terms of k-secants and k-tangents (k a positive integer) of the Veronese variety [3] and we prove that only the k-tangent structuration provides a coherent structure compatible with that of Ref. [3].

[1] W. Dür et al., Phys. Rev. A **62**, 062314 (2000). [2] T. Bastin et al., Phys. Rev. Lett. **103**, 070503 (2009). [3] M. Sanz et al., J. Phys. A: Math. Theor. **50**, 195303 (2017).

Q 8.7 Mon 16:30 Empore Lichthof

What channels can be implemented without a reference frame? — •Fynn Otto — University of Siegen, Germany

Quantum reference frames are needed for communication tasks for which the method of information encoding matters. In contrast to – for example – sending integers, reference frames are needed for communicating, e.g. quantum phases or directional information. Even if a classical communication link between two parties is established, it is not possible to send a *direction in space*.

Lacking a reference frame limits the set of operations that can be performed deterministically. Changing reference frames is equivalent to the passive evolution of a state under the unitary operator $U(g)$, representing the transformation g. The transformations between reference frames form a group G, and allowed frame-agnostic channels turn out to be G-covariant: the channel $\mathcal{E}$ must commute with every $U(g)$.

Here we investigate the reachable states for two important cases: lacking a phase reference (corresponding to the group $G = U(1)$) and lacking a Cartesian frame alignment ($G = SU(2)$). Examples of G-covariant state transformation are provided along with possible classification and interpretation of the reachability structure.

Q 8.8 Mon 16:30 Empore Lichthof

Leveraging noisy physical observables with machine learning. — •Adisorn Panasawatwong, Ulf Saalman, and Jan-Michael Rost — Max-Planck-Institute for the Physics of Complex Systems

A noisy light pulse containing many frequencies leads to deterministic electron dynamics in the illuminated target, whose response will also look noisy. At first glance, it cannot be distinguished from a random signal which results from fully chaotic dynamics. While the latter contains little information, the former contains valuable information about the target system, even more than its (linear) response to a Fourier-limited single-frequency pulse.

We are developing a machine learning-based approach which can distinguish the two kinds of noisy signals according to their actual information content: their complexity. Without using entropy, we show emergence of information by interpreting the result from auto-encoder.

Knowing the degree of complexity in the signal enables us to develop networks tailored to extract the amount of information about the target which is contained in the noisy observable due to its complexity.

Q 8.9 Mon 16:30 Empore Lichthof

Entanglement in free fermion systems — Lexin Ding[1,2], •Gesa Dünnweber[1,2], and Christian Schilling[1,2] — [1]Faculty of Physics, Arnold Sommerfeld Centre for Theoretical Physics (ASC), Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Entanglement is becoming an increasingly important resource for the realisation of quantum information tasks. Several measures of mode entanglement have been proposed for fermionic systems.

We consider a spinful free fermion chain under nearest neighbour hopping and determine an analytic measure of the resulting site-site entanglement. Including in particular the restrictions imposed by parity or particle number superselection rules, we study how various factors affect the accessible entanglement. This approach is extended to a model that includes an additional hopping term where we investigate the evolution of entanglement across a Lifshitz-type transition. Relating orbital entanglement to the concept of locality within a molecule, we present numerical results for a hydrogen chain.

Finally, we are interested in protocols for extracting entanglement from fermionic systems such as entanglement swapping, where superselection rules demand modifications to the established protocols for qubits.

Q 8.10 Mon 16:30 Empore Lichthof

Quantum Key Distribution from Bound Entanglement — •Zeynab Tavakoli[1] and Gláucia Murta[2] — [1]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany — [2]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

Quantum key distribution (QKD) aims to secure communication and establish a secret key between two honest parties. A secret key is a string of independent and random bits known to both parties. Key distillation in QKD is related to entanglement distillation; by distilling a maximally entangled state, one can get the key by measuring it. The belief was that achieving security is equivalent to distilling maximally entangled states. However, Authors of [Phys.Rev.Lett.80,5239,(2005)] show bound entangled states are usable to obtain key. Bound entangled states are quantum states that no maximally entangled states can be distilled from them using LOCC. Bound entangled states used in QKD have entanglement, which protects correlations from the environment. However, the entanglement is so twisted that it cannot be brought into a maximally entangled state. In this work, we studied known examples of bound entangled states useful for QKD. In particular, we investigate the noise tolerance of the corresponding QKD protocol, construct new bound entangled states around the original examples, and investigate their achievable key rates. Finally, we investigate if bound entangled states can be used in a simple QKD protocol where a single copy of the state is distributed and measured each round.

Q 8.11 Mon 16:30 Empore Lichthof

Randomness Certification for Multipartite Arbitrary Dimensional Systems — Yu Xiang[1,2], •Yi Li[1], and Qiongyi He[1,2,3] — [1]State Key Laboratory for Mesoscopic Physics, School of Physics, Frontiers Science Center for Nano-optoelectronics, and Collaborative Innovation Center of Quantum Matter, Peking University, Beijing 100871, China — [2]Collaborative Innovation Center of Extreme Optics, Shanxi University, Taiyuan, Shanxi 030006, China — [3]Peking University Yangtze Delta Institute of Optoelectronics, Nantong, Jiangsu 226010, China

We first present a method to certify the randomness generated in multipartite arbitrary dimensional systems, closely to the actual situation where some of the untrusted sides are measured locally. The proposed method also provides a hierarchy of upper and lower bounds of randomness with different assumptions. Comparing with the bipartite scenario, our result shows more randomness can be certified in this asymmetric network. Surprisingly, for some systems, we find that there exists nonzero certified randomness on the untrusted parties together, even though no randomness can be induced in either mode individually, which implies randomness in the multipartite network can be used for some security tasks in the future. The ease of our method is also demonstrated by adopting some existing experimental data. Finally, we prove that multipartite steering is necessary for generating randomness in the asymmetric network.

Q 8.12 Mon 16:30 Empore Lichthof

Markovian master equations beyond the adiabatic and inertial limit — •Josias Langbehn[1], Roie Dann[2], Raphael Menu[3], Giovanna Morigi[3], Ronnie Kosloff[2], and Christiane Koch[1] — [1]Freie Universität Berlin, Berlin — [2]Institute of Chemistry, Hebrew University, Jerusalem — [3]Universität des Saarlandes, Saarbrücken

Markovian master equations in Gorini-Kossakowski-Sudarshan-Lindblad (GKLS) form can accurately describe the dynamics of many open quantum systems ranging from optical to solid state systems. Adding a drive to the system complicates the derivation of any such master equation. The Markovian framework has been extended to drives in the adiabatic regime [1] and beyond that to inertial drives within the "non-adiabatic master equation" (NAME) [2]. The aim of this work is to extend this framework to drives that go even beyond the inertial limit by introducing a numerical scheme for finding an eigenoperator basis. In principle this allows for arbitrary drives, going as far as Markovian master equations in GKLS form remain valid. Moreover, the numerical scheme allows treating situations where no inertial solution can be found analytically. This opens the door for optimal control tasks where the time-dependency of the optimal drives may not be adiabatic/ inertial. We observe significant deviations between the NAME and the adiabatic/ inertial limit in multiple exemplary systems considered.

[1] Albash, T., Boixo, S., Lidar, D. A. & Zanardi, P. New J. Phys. 14, 123016 (2012). [2] Dann, R., Levy, A. & Kosloff, R. Phys. Rev. A 98, 052129 (2018).

Q 8.13 Mon 16:30 Empore Lichthof

Mimicking non-Markovian dynamics using the stochastic surrogate Hamiltonian — •Jonas Fischer and Christiane Koch — Freie Universität Berlin

Some control tasks, like qubit reset, demand interaction between the system and environment. In order to perform these tasks quickly, it is beneficial if this coupling is as strong as possible. Typically, this leads to non-Markovian dynamics, for which there is no unified propagation method so far.

One possible candidate is the surrogate Hamiltonian. The real environment is substituted by a collection of two-level systems that capture the influence of the real environment on the system. This allows for the propagation of the full Hilbert space, allowing for the description of non-Markovian dynamics.

Due to the truncation of the Hilbert-space, this method is limited to short timescales. At a certain point in time, the environmental modes will saturate and recurrences in the system dynamics will occur. The stochastic surrogate Hamiltonian is aiming to resolve this issue by randomly resetting the environmental modes into a thermal state. These resets should be performed in such a way that the recurrences get suppressed, but at the same time, they should destroy as few correlations as possible. We present a reset method that reproduces the correct reduced density matrices for both the reset mode and the other environmental modes.

Q 8.14 Mon 16:30 Empore Lichthof

Quantum transport in noisy networks of coupled harmonic oscillators — •Emma King, Raphael Menu, and Giovanna Morigi — Theoretische Physik, Universitat des Saarlandes, D-66123 Saarbruecken, Germany

In recent years rapid progress has been made towards the realisation of scalable quantum computers. While devices with an increasing number of qubits are being realised, the present size does not yet allow for the efficient implementation of error-correction schemes. This highlights the importance of understanding the role of an environment on the target quantum coherent dynamics. In this work we address the question as to which properties of an external environment are detrimental, and, in contrast, which properties can be used as resources for quantum transport. For this purpose we consider two chains of coupled harmonic oscillators with long range interactions that decay in a power law fashion. The one chain acts as the system while the other is the environment. In this setting we derive a quantum master equation starting from the Liouville-von Neumann equation and identify the requirements on the environment for which the master equation has the Lindblad form. We then analyse transport in the chain as a function of the environment characteristics, identifying the regime(s) in which it leads to faster propagation of information along the chain.

Q 8.15 Mon 16:30 Empore Lichthof

Engineering a heat engine purely driven by quantum coherence — •Stefan Aimet — Imperial College London, London, United Kingdom — FU Berlin, Berlin, Germany

The question of whether quantum coherence is a resource beneficial or detrimental to the performance of quantum heat engines has been thoroughly studied but remains undecided. To isolate the contribution of coherence, we analyse the performance of a purely coherence-driven quantum heat engine, a device that does not include any heat flow during the thermodynamic cycle. The engine is powered by the coherence of a multi-qubit system, where each qubit is charged via interaction with a coherence bath using the Jaynes-Cummings model. We demonstrate that optimal coherence charging and hence extractable work is achieved when the coherence bath has an intermediate degree of coherence. In our model, the exctractable work is maximised when four copies of the charged qubits are used. Meanwhile, the efficiency of the engine, given by the extractable work per input coherence flow, is optimised by avoiding coherence being stored in the system-bath correlations that is inaccessible to work. We numerically find that the highest efficiency is obtained for slightly lower temperatures and weaker system-bath coupling than those for optimal coherence charging.

Q 8.16 Mon 16:30 Empore Lichthof

Design of a 4-party active base choice phase-coding quantum key distribution multi-user hub — •Adrian Klute, Maximilian Tippmann, Lucas Bialowons, Erik Fitzke, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

In the developing field of secure quantum communication, several quantum key distribution (QKD) systems have been tested with various protocols. However, building scalable QKD systems with more than 2 parties is a challenging task. We recently presented a 4-party star-shaped quantum hub system, which is based on time-bin entanglement. The crucial part in this setup is the precise building of interferometers. Precise building methods with sufficient reliability are needed to exchange keys with low quantum bit error rate between all user pairs of the hub. Not only the building method but also a suitable design choice of the interferometer can reduce uncertainties in the building process. In that sense we are discussing the technological challenges of two known interferometer designs for an active phase-coding protocol, a Sagnac-Michelson and a Sagnac-Mach-Zehnder configuration. We present first results to assess the success of the building method that we used.

Q 8.17 Mon 16:30 Empore Lichthof

Towards a city-wide quantum key distribution network with a multi-user phase-time coding quantum key hub — •Maximilian Tippmann, Erik Fitzke, Till Dolejsky, Florian Niederschuh, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

Quantum key distribution (QKD) paves a way to make today's IT-infrastructure resilient against future attacks e.g. from quantum computers. Various QKD protocols and setups have been tested over the last decades. However, most experiments focus on two-user systems, thus not allowing an easy scaling to multiple users. Here, we report on a quantum key hub implementing the phase-time protocol with a central untrusted node for simultaneous pairwise key exchange, tested with four users, but readily scalable to more than 100 users. The central untrusted node consists of an entangled photon pair source, and provides high-flexibility, allowing plug-and-play reconfiguration of the connected parties. Furthermore, the setup has been tested with real-world deployed fiber demonstrating the practicability of our approach. Going towards a city-wide deployment, we look into setup specific issues, including post-processing and alignment of the setup, arising from the distribution of the communicating parties to a city-wide scale.

Q 8.18 Mon 16:30 Empore Lichthof

System Components for Single-Photon Quantum Key Distribution in the Telecom C-band — •Timm Gao, Mareike Lach, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

We report on the evaluation of system components for single-photon based quantum communication in the telecom C-band. We evaluate the performance of different hardware components for quantum key distribution. Special emphasis lies here on the receiver module, where free-space and fiber-based approaches are comparatively discussed.

Q 8.19 Mon 16:30 Empore Lichthof

Night Sky Background Measurement for Quantum Key Distribution — •Rengaraj Govindaraj[1,2], Michael Auer[1,2,3], Adomas Baliuka[1,2], Peter Freiwang[1,2], Lukas knips[1,2,4], and Harald Weinfurter[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799, München, Germany — [2]Munich Center for Quantum Science and Technology, 80799, München, Germany — [3]Universität der Bundeswehr, 85577 Neubiberg, Germany — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Free-space satellite-to-ground quantum key distribution (QKD) enables two authenticated parties - potentially separated by global distances - to exchange a secret key that can be used for symmetric cryptography. However, the performance of free-space QKD crucially depends on the quantum bit error ratio (QBER) and hence on the contributions of background light sources such as light from natural sources as the sun or stars as well as from artificial light sources. As those noise contributions vary with time of day, season, weather and location, their study is important for estimating future QKD missions. We here present our experimental method to map the night sky background in terms of its brightness in the spectral bands around 850nm and 1550nm and discuss the implications for satellite-based QKD.

Q 8.20 Mon 16:30 Empore Lichthof

Designing versatile and performant DM-CV QKD systems for the QuNET initiative — •Stefan Richter[1,2], Ömer Bayraktar[1,2], Kevin Jaksch[1,2], Bastian Hacker[1,2], Imran Khan[1,2,5], Emanuel Eichhammer[1,5], Emmeran Sollner[1,5], Twesh Upadhyaya[3], Jie Lin[3], Norbert Lütkenhaus[3], Florian Kanitschar[4], Stefan Petscharnig[4], Thomas Grafenauer[4], Ömer Bernhard[4], Christoph Pacher[4], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Chair of Optical Quantum Technologies, Department of Physics, Friedrich Alexander University Erlangen-Nuremberg, Erlangen, Germany — [2]Quantum Information Processing Group, MPI for the Science of Light, Erlangen, Germany — [3]Institute for Quantum Computing, Dept. of Physics and Astronomy, University of Waterloo, Canada — [4]Security & Communication Technologies Unit, Austrian Institute of Technology, Vienna, Austria — [5]now with KEEQuant GmbH, Fürth, Germany

Continuous-variable quantum key distribution (CV-QKD) is a key technology for guarding critical communication links against the rapidly growing threat of large-scale quantum computers. We present our progress in implementing a versatile and performant CV-QKD system designed for metropolitan fiber optical networks. Important performance indicators estimated during a public technology demonstration in August 2021 and recent improvements will be discussed. We also highlight special design aspects and challenges of the implementation, in particular with regard to stability and error correction requirements.

Q 8.21 Mon 16:30 Empore Lichthof

Night Sky Background Measurement for Quantum Key Distribution — •Rengaraj Govindaraj[1,2], Michael Auer[1,2,3], Adomas Baliuka[1,2], Peter Freiwang[1,2], Lukas Knips[1,2,4], and Harald Weinfurter[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799, München, Germany — [2]Munich Center for Quantum Science and Technology, 80799, München, Germany — [3]Universität der Bundeswehr, 85577 Neubiberg, Germany — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Free-space satellite-to-ground quantum key distribution (QKD) enables two authenticated parties - potentially separated by global distances - to exchange a secret key that can be used for symmetric cryptography. However, the performance of free-space QKD crucially depends on the quantum bit error ratio (QBER) and hence on the contributions of background light sources such as sun or stars as well as artificial light sources. As those noise contributions vary with time of day, season, weather and location, their study is important for planning the location and performance of ground station's future QKD missions. We here present our experimental method and device to map the night sky background in terms of its brightness in the spectral bands around 850nm and 1550nm and discuss the implications for satellite-based QKD.

Q 8.22 Mon 16:30 Empore Lichthof

Towards quantum communication over intercity optical fiber link — •Ali Hreibi, Ann-Kathrin Kniggendorf, Harald Schnatz, and Stefan Kück — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

We report on the status of the PTB's work to establish a quantum communication test bed between Braunschweig and Hanover (the "Niedersachsen Quantum Link"). In this context, we present an overview of the quantum key distribution (QKD) system based on the BBM92 protocol set up at PTB and the test of quantum communication via optical fiber up to 90 km in length. The QKD system generates Polarization-entangled photon pairs using the nonlinear optical process of spontaneous parametric down-conversion, and transmits the entangled photon pairs (signal, and idler) to a local and a remote location through the optical fiber. Photons are detected on both sides and measurement data is processed by the system in order to generate a secure quantum encryption key. The Communications security relies on the laws of quantum mechanics and the non-cloning theorem which prevents a quantum state from being copied or measured without disturbing it.

Q 8.23 Mon 16:30 Empore Lichthof

The Ideal Wavelength for Daylight Free-Space Quantum Key Distribution — •Mostafa Abasifard[1], Chanaprom Cholsuk[1], Roberto G. Pousa[2], Anand Kumar[1], Ashkan Zand[1], Daniel K. L. Oi[2], and Tobias Vogl[1,3] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany — [2]Computational Nonlinear and Quantum Optics, SUPA Department of Physics, University of Strathclyde, Glasgow G4 0NG, United Kingdom — [3]Fraunhofer-Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany

Quantum key distribution (QKD) has matured from proof-of-principle demonstrations in the lab to commercial systems. Intercontinental quantum communication distances have been bridged with satellites. Satellite-based quantum links can only operate during the night, as the sunlight would otherwise saturate the detectors used to measure the quantum states. For high data rates and continuous availability, operation during daylight is desirable.

We model a satellite-to-ground quantum channel for the BB84 protocol in order to determine the optimal wavelength for daytime free-space QKD. We look at the 400 nm to 1700 nm wavelength range and find extractable secret bits per signal for several light sources. As expected, the Fraunhofer lines appear as peaks in the spectrum of the secure data rate. For the ideal wavelength, we also propose a true single photon source, based on a resonator coupled color center in hexagonal boron nitride.

Q 8.24 Mon 16:30 Empore Lichthof

Dynamic Polarization State Preparation for Single-Photon Quantum Cryptography — •Koray Kaymazlar, Tim Gao, Daniel Vajner, Lucas Rickert, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Quantum key distribution (QKD) systems using polarization encoding require fast modulation of the polarization states of single-photon pulses. Here, we present a setup for preparing the polarization of single photons dynamically. The system consists of electronics based on a field programmable gate array (FPGA) and a digital to analog converter (DAC) driving a free space electro optic modulator (EOM) with 500 MHz bandwidth. We characterize and optimize the performance of this setup in terms of extinction ratio and repetition rate and discuss its suitability for applications in QKD experiments.

Q 8.25 Mon 16:30 Empore Lichthof

Investigation of the phase-space distribution of the BPSK-encoded optical coherent signal from a geostationary satellite — •Hüseyin Vural[1], Conrad Rössler[1], Andrew Reeves[2], Bastian Hacker[1], Thomas Dirmeier[1], Karen Saucke[3], and Christoph Marquardt[1] — [1]Max-Planck Institut für die Physik des Lichts (MPL) — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR) - Institut für Kommunikation und Navigation — [3]Tesat Spacecom

Coherent optical communication between a satellite and a terrestrial ground station can facilitate classical as well as quantum-limited communication. In a recent paper, we demonstrated quantum limited signals from a geostationary satellite in a homodyning measurement, that indicate the viability of long-distance quantum key distribution (QKD) and global secure communication. Here, we investigate the phase-space distribution of the BPSK-encoded coherent signal from the same satellite, however at an optical ground station in an urban area and by heterodyning the quantum signal with a free running commercial laser. Our results indicate that scalable solutions for quantum-limited signals may be in reach.

Q 8.26 Mon 16:30 Empore Lichthof

Single atoms in optical cavities as source for multiphoton graph states — •Leonardo Ruscio, Philip Thomas, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Generating multiphoton entangled states is an essential step for the development of quantum information protocols such as measurement based quantum computation. Thanks to their weakly interacting nature, entangled photons are in fact ideal qubit carriers. So far, the most successful source of entangled photons has been spontaneous parametric down conversion, where scaling up is dramatically limited by its intrinsically probabilistic nature. We experimentally demonstrate the feasibility of a single Rubidium atom in an optical cavity as an efficient source of multiphoton graph states [1]. We use the atom as a memory mediating the entanglement generation between the photons and we efficiently grow GHZ states of up to 14 photons and linear cluster states of up to 12 photons. With an overall efficiency of 43%, our experiment opens a way towards scalable measurement-based quantum computation and communication, where this scheme could be for example extended to two atoms in a cavity to generate higher-dimensional cluster states.

[1] P.Thomas et al., Nature 608, 677-681 (2022)

Q 8.27 Mon 16:30 Empore Lichthof

Driven Gaussian Quantum Walks — •Philip Held[1], Melanie Engelkemeier[1], Syamsundar De[1], Sonja Barkhofen[1], Jan Sperling[2], and Christine Silberhorn[1] — [1]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany — [2]Paderborn University, Theoretical Quantum Science, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

Quantum walks function as essential means to implement quantum simulators, allowing one to study complex and often directly inaccessible quantum processes in controllable systems. In this contribution, the new notion of a driven Gaussian quantum walk is presented. Here, instead of a unitary operation, a nonlinear map is used to describe the operation of the quantum walk in optical settings. Including nonlinear elements as core components, this type of quantum walk introduces quantumness of the dynamic itself, regardless of the input state. A parametric down-conversion is chosen as the nonlinear operation, introducing new walkers and squeezing during the evolution. To characterize nonlinear, quantum, and quantum-nonlinear effects following from this evolution, a full framework for driven Gaussian quantum walks is developed. In particular, the generation and amplification of highly multimode entanglement, squeezing, and other quantum effects are studied over the duration of the nonlinear walk.

Q 8.28 Mon 16:30 Empore Lichthof

Quantum Simulation of Biased Open System Dynamics — •Marcel Cech[1], Federico Carollo[1], and Igor Lesanovsky[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We present a protocol for the generation of rare quantum jump trajectories on a digital quantum simulator. Our approach allows to bias open system dynamics with regard to any, even non-linear, function, e.g. it can increase or decrease the likelihood of trajectories with specific emission patterns and correlation properties. We derive the dynamical map of the corresponding biased process. Moreover, we show how the biased open systems dynamics can be implemented on an IBM quantum processor. Using as an example an open two-level system we discuss challenges and current limitations of this approach.

Q 8.29 Mon 16:30 Empore Lichthof

Preparing ground states of the Fermi-Hubbard model with shallow quantum circuits — •Tobias Schmale[1], Bence Temesi[1], Hamed Saberi[1], and Hendrik Weimer[2,1] — [1]Institut für Theoretische Physik, Hannover, Germany — [2]Institut für Theoretische Physik, TU Berlin, Germany

The 2D Fermi-Hubbard model is a paradigmatic model in condensed matter physics, potentially holding the key to understanding high-temperature superconductivity. We turn to digital quantum simulations of the model, as classical simulation methods remain prohibitively challenging. We investigate a strategy for adiabatic preparation of the ground state by shallow quantum circuits running in constant time on a highly parallelized architecture. Additionally, we consider a simplified architecture consisting of a single computing register in a trapped-ion architecture based on ion shuttling, where we find that a single auxiliary qubit is sufficient to implement the mapping from fermions to qubits. We show that these architectures naturally allow for the realization of extensions to the Hubbard model such as next-nearest-neighbor hopping, which might be crucial to stabilize d-wave superconductivity.

Q 8.30 Mon 16:30 Empore Lichthof

Quantum Simulations: Endeavours with trapped ions in a 2D array and a Linear Paul trap — •Apurba Das, Deviprasath Palani, Florian Hasse, Maharshi Pran Bora, Lucas Eisenhart, Tobias Spanke, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Freiburg, Deutschland

Individual ions, trapped in a customised trap architecture offer one of the most promising platforms for quantum simulations[1]. In our lab, applying suitable local and global control fields on the trapped ions, we set up and tune increasingly complex quantum systems with a high level of control in a 2D array on a Surface electrode radio frequency trap and in a linear Paul trap. In our 2D array, we realize the Floquet-engineered coupling of adjacent sites through local manipulation of trapping potentials[2] and tuning of the system in real-time and interference of coherent states over large amplitudes[3]. Here, we also demonstrate the relocation of ions in a deterministic manner. In the Linear Paul Trap, we show the preparation of two ions in a squeezed state of motion featuring entanglement of the ions' motional degrees. This leads to the realization of an experimental analogue of the particle pair creation during cosmic inflation in the early universe[4]. In addition, we move towards the transfer of entanglement of motional degrees of freedom to internal degree of freedom.

[1] T. Schaetz et al., New J. Phs. 15, 085009 (2013)
[2] P. Kiefer et al., PRL 123, 213605 (2019)
[3] F. Hakelberg et al., PRL 123, 100504 (2019)
[4] M. Wittemer et al., PRL 123, 180502 (2019)

Q 8.31 Mon 16:30 Empore Lichthof

Programmable cooling on noisy quantum computers: Implementation and error analysis — •Imane El Achchi[1], Anne Matthies[1], Achim Rosch[1], Mark Rudner[2], and Erez Berg[3] — [1]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany — [2]University of Washington, Seattle, WA 98195-1560, US — [3]Weizmann Institute of Science, Rehovot, 76100, Israel

Recent advances in quantum computing provide a vast playground for the application of quantum algorithms on noisy intermediate-scale quantum devices. Here, we test the performance of the programmable adiabatic demagnetization protocol proposed in Ref. [1] on IBM's quantum devices. The cooling protocol prepares low-energy states for any gapped Hamiltonian independently of the system's initial state. Half the qubits simulate the system, and the other a bath in a strong Zeeman field, initialized in the polarized state. Entropy is transferred from the system to the bath by slowly decreasing the Zeeman field. Finally, the bath spins are measured and reset to the polarized state. The process is repeated throughout the protocol until a low-energy state of the system is reached. Cooling protocols are generally stable against low noise, making them a promising application for near-term quantum computers. We experimentally observe a cooling effect for the available small system size and limited gate depth on the IBM quantum device using quantum optimal control. Furthermore, we analytically analyze the dynamics of the cooling protocol to find a dark state of the corresponding quantum channel.

[1] arxiv: 2210.17256

Q 8.32 Mon 16:30 Empore Lichthof

Treating finite system-bath coupling using the hierarchy-of-pure-states approach — •Johann Assmus, Tobias Becker, and André Eckardt — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany

Open quantum system dynamics can be described by master equations for the system's reduced density matrix, however, the derivation of these equations often requires some assumptions like the Born-Markov-approximation. The hierarchy-of-pure-states approach is an alternative to master equations where the system is described by a stochastic ensemble of pure states and additional auxiliary states [1]. Since the dynamics of these pure states can be derived without any approximations, this approach is numerically exact. However, an approximation is made, by allowing for a finite number of auxiliary states. We compare the solutions of this method with the exact dynamics of a damped harmonic oscillator to examine its behaviour in regards to the number of hierarchies and other parameters.

[1] D. Süß, A. Eisfeld, W.T. Strunz, Phys. Rev. Lett. 113, 150403 (2014)

Q 8.33 Mon 16:30 Empore Lichthof

Quantisation and breakdown of topological transport in the Hubbard-Thouless pump — •Marius Gächter, Zijie Zhu, Anne-Sophie Walter, Konrad Viebahn, Stephan Roschinski, Joaquín Minguzzi, Kilian Sandholzer, and Tilman Esslinger — ETH, Zurich, Switzerland

Predicting the fate of topologically protected transport in the strongly correlated regime represents a central challenge within condensed matter physics. On the one hand, free-fermion energy bands and their geometric properties give rise to quantised transport phenomena, such as the quantum Hall effect and its dynamic analogon, the Thouless pump. The quantisation in these systems is considered robust against perturbations that commute with a protecting symmetry. On the other hand, interparticle interactions support strongly correlated states of matter, which often preclude particle transport, exemplified by the Mott transition in the Hubbard model. Will topology prevail in the presence of strong correlations? Here, we systematically probe the response of a topological Thouless pump to Hubbard interactions in an ultracold-atom experiment. We identify three distinct regimes, that is, pair pumping for strongly attractive interactions, quantised pumping for weak and moderate interactions, as well as the breakdown of transport for strong repulsive Hubbard U. Our experiments pave the way for investigating edge effects in interacting topological insulators, as well as interaction-induced topological phases with no counterpart in free-fermion systems.

Q 8.34 Mon 16:30 Empore Lichthof

Switching Topological State via Ferroelectric Polarization Field — •Jiabao Yang and Niels B. M. Schröter — Max-Planck-Institute of Microstructure Physics, Weinberg 2, 06120 Halle(Saale), Germany

The quantum spin hall insulator (QSHI) has shown great potential in low-dissipation spintronics and topological quantum computing, most of which highly rely on the emergency of topological edge state. Two common achieving methods, electric gating and strain effect are both challenging though the former requires continuous energy consumption and the latter needs precise control of strain. Two-dimensional(2D) ferroelectric material (FE), a kind of material with spontaneous and switchable charging polarization, can bring out a controllable topological order of 2D heterostructure when stacked with a heavy-element trivial insulator. The built-in electric field leads to new band alignment of the heterostructure, and band inversion occurs at the conduction band minimum of 2D FE and valence band maximum of TI. With the help of the robust interlayer spin-orbit coupling effect, the band gap can be opened. α-In2Se3, a typical ferroelectric material with a quite large polarizing built-in electric field(1.35eV), is an ideal substrate for monolayer WTe2. What is expected is the new topological state occurs in the van der Waals heterostructure around the gamma point and new non-volatile control of topological states.

Q 8.35 Mon 16:30 Empore Lichthof

Noise-assisted adiabatic quantum search algorithm: a study via quantum trajectories — •Raphaël Menu[1], Christiane P. Koch[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbr *ucken, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany

Adiabatic quantum computing offers a precious alternative to quantum circuits for the implementation of quantum search algorithms. Indeed, while circuits require an oracle, namely a black box, to test whether the algorithm converged towards the target state, adiabatic quantum search algorithms performs the calculation via the adiabatic preparation of the ground state of a simple effective two-level system. Yet, such an approach is not flawless since it requires a large annealing time so that transitions out of the ground state are suppressed, and therefore one may reach time scales when the effects of the environment become relevant.

In this work, we study by the means of the framework of quantum trajectories (Monte Carlo wavefunction) the adiabatic implementation of the Grover search algorithm, and investigate how one can improve the performance of the search via the coupling of the computation qubit to an ancilla, leading to a shortest annealing time and a correction of the computational errors.

Q 8.36 Mon 16:30 Empore Lichthof

Microwave quantum memory based on rare earth doped crystal — •Jianpeng Chen[1,2,3], Ana Strinic[1,2,3], Achim Marx[1,2],

Kirill G. Fedorov[1,2], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Quantum memory is essential in future quantum technologies, such as quantum computing circuits and quantum communication links. Specifically, Crystals doped with rare earth ions are promising competitive candidates due to their long coherence times [1] and potential multiplexing capability [2]. Here, we use a transmission line to couple microwave signals to rare earth ion dopants in yttrium orthosilicate crystals (Y2SiO5) at 10 mK. We present experimental results on storing coherent microwave states using the spin echo protocol. We will discuss the resulting coherence time and the impact of the transmission line design on the efficiency of the quantum information storage and its multimodality potential. We acknowledge financial support from the Federal Ministry of Education and Research of Germany (project number 16KISQ036). [1] Zhong, M, Nature 517, 177*180 (2015). [2] Antonio Ortu et al.Quantum Sci. Technol. 7 035024 2022.

Q 8.37 Mon 16:30 Empore Lichthof

Towards on-chip microwave-to-telecom transduction based on erbium-doped silicon — •Daniele Lopriore[1,2] and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

The development of a device that converts microwave to optical photons at a telecommunication wavelength would be a key enabler for the communication between remote quantum computers. In this context, we are investigating erbium ensembles doped into nanophotonic silicon waveguides. This novel hardware platform features a unique combination of a small inhomogeneous broadening and an exceptional optical coherence even in nanostructured materials [1]. In an external magnetic field, the ground and excited states are split into doublets, which allows the erbium ensemble to act as the nonlinear medium mediating an efficient conversion process [2,3]. To this end, we plan to enhance both the microwave and the telecom transitions with resonators of high quality factor, fabricated on the same silicon chip. By optimizing the resonator geometries in order to maximize the overlap between the resonating fields and the erbium dopants, we aim to achieve transduction efficiencies approaching unity [3]. This would pave the way for the entanglement of superconducting qubits in remote cryostats.

[1] A. Gritsch, et al. Phys.Rev.X 12, 041009 (2022).
[2] L. Williamson, et al. Phys.Rev.Lett. 113, 203601 (2014).
[3] C. O'Brien, et al. Phys.Rev.Lett. 113, 063603 (2014).

Q 8.38 Mon 16:30 Empore Lichthof

Towards an efficient Quantum Network - Silicon Vacancy Color Centers in Diamond — •Donika Imeri[1,2], Tuncay Ulas[1], Sunil Kumar Mahato[1,2], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg

Quantum networks combine a high level of security and the ability to scale up the qubit number which is crucial for quantum information processing. These networks contain nodes that store information. Quantum communication can be enabled by linking these nodes via entanglement. Silicon vacancy color centers in diamonds are promising components for optically connected quantum processors. The point defects establish an efficient optical interface and display a protective inversion symmetry. Therefore, the incorporation of nanophotonic structures, as well as coherent resonators, is possible. This can be used to generate entanglement between spin and photonic qubits. Long coherence times are a benefit, however, this includes the challenge of working in a cryogenic environment. Here, we present a platform to generate efficient and secure quantum communication by connecting multiple quantum processors.

Q 8.39 Mon 16:30 Empore Lichthof

Towards active stabilization of magnetic fields for trapped ions — •Lucas Eisenhart, Deviprasath Palani, Fabian Thielemann, Florian Hasse, Apurba Das, Ulrich Warring, Tobias Spanke, and Tobias Schaetz — Physikalisches Institut, Freiburg, Deutschland

When experimenting with trapped ions, it can be of great importance to generate magnetic fields that are highly stable, for example, when exploiting the electron degree of freedom in quantum applications. For this we characterize magnetic field sensors, with the help of which we may be able to adapt the coil current in our experiments to reduce field fluctuations. For magnetic field amplitudes in a range from 0.1G to 10^5G we use a Hall sensor with a sensitivity of 0.02mV/G and and a bandwidth that reaches up to 200kHz. For smaller magnetic field amplitudes in a range from 60μG to 10G we use a fluxgate sensor module that has a sensitivity of 1V/G and a bandwidth of up to 1kHz. We present our benchmark results of the hall- and fluxgate-sensor within our test environment.

Q 8.40 Mon 16:30 Empore Lichthof

High-order series expansions and crystalline structures for Rydberg atom arrays — •Duft Antonia, Jan Koziol, Matthias Mühlhauser, Patrick Adelhardt, and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

We investigate a model of hardcore bosons on the links of a Kagome lattice subject to a long-range decaying van-der-Waals interaction. This model is known to be the relevant microscopic description of Rydberg atom arrays excited by a detuned laser field which has been realized in experiments recently. Particular interest lies on this system as it is an engineerable quantum platform which has been predicted to to host a topological phase. We investigate the quantum phase diagram for different limiting cases with a main focus on the low interaction-strength limit where we apply high-order linked cluster expansions.

Q 8.41 Mon 16:30 Empore Lichthof

Numerical investigation of the Ising model in a light-induced quantized transverse field — •Anja Langheld and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We investigate the Ising model in a light-induced quantized transverse field [1] with a particular focus on antiferromagnetic, potentially frustrated Ising interactions. Using exact diagonalization, we provide data for the antiferromagnetic chain in a longitudinal field that is inconsistent with earlier results coming from mean-field considerations [2]. In order to study the model on frustrated, two-dimensional lattice geometries, we extend the mean-field calculation and develop a quantum Monte Carlo update based on the recently introduced wormhole update [3], for which the photons are integrated out. By this means, the photons induce a retarded spin-spin interaction in imaginary time that is also non-local in space in contrast to the Ising interaction inherent to the model.

[1] J. Rohn et al., Phys. Rev. Research 2, 023131 (2020)
[2] Y. Zhang et al., Sci Rep 4, 4083 (2014)
[3] M. Weber et al., Phys. Rev. Lett. 119, 097401 (2017)

Q 8.42 Mon 16:30 Empore Lichthof

Luttinger's Theorem in the One-Dimensional tJ-model — •Annika Böhler[1,2], Henning Schlömer[1,2], and Fabian Grusdt[1,2] — [1]Ludwig-Maximilians University, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

The Hubbard model in one dimension is known to exhibit spin charge separation, which has recently been observed in settings of ultracold fermions in optical lattices. Another signature of spin-charge separation in a lattice, that has not been directly observed thus far, is constituted by a change of the Fermi momentum. Luttinger's theorem relates the volume of the Fermi surface - and therefore the Fermi momentum - to the underlying particle density of the system. Here we discuss a proof of the theorem [M. Oshikawa, Phys. Rev. Lett. 84 (2000), 3370] in the presence of spin charge separation and evaluate whether it provides a tool to distinguish between qualitatively distinct spin-1/2 liquids and spinless chargon liquids via their different Fermi momenta. We show that Friedel oscillations of the density at the edge of a system can be used to directly observe the change of Fermi momentum, reflecting a qualitative change in the nature of charge carriers which we associate with an emergent U(1) symmetry corresponding to the total number of holes in the large-U limit of the Hubbard model.

Q 8.43 Mon 16:30 Empore Lichthof

Guided variational quantum algorithm for time evolution in dynamical mean field theory — •Stefan Wolf[1], Michael J. Hartmann[1], and Martin Eckstein[2] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]I. Institute of Theoretical Physics, Department of Physics, University of Hamburg

Dynamical mean-field theory (DMFT) is a useful tool to treat models of strongly correlated fermions like the Hubbard model. The lattice of the model is replaced by a single-impurity site embedded in an effective bath. The resulting single impurity Anderson model (SIAM) can then be solved self-consistently with a quantum-classical hybrid algorithm. This procedure involves repeatedly preparing the ground state on a quantum computer and evolving it in time. We propose an approximation of the time evolution operator by a Hamiltonian variational ansatz. The parameters of the ansatz are obtained via a variational quantum algorithm that utilizes a small number of Trotter steps, given by the Suzuki-Trotter expansion of the time evolution operator, to guide the evolution of the parameters. The cost function is evaluated by measuring a single ancilla qubit using the Hadamard test, thus reducing the required number of measurements compared to other approaches. The resulting circuit for the time evolution is shallower than a comparable Suzuki-Trotter expansion. We show results for two-site DMFT with half-filling. We further looked into the possibility to extend the approach for the impurity model with more than one bath site and away from half-filling.

Q 8.44 Mon 16:30 Empore Lichthof

Measurement Induced State Preparation — •Daniel Alcalde Puente — PGI8, Wilhelm-Johnen-Straße 52428 Jülich

This work explores the protocol proposed in (Roy, Sthitadhi, et al. "Measurement-induced steering of quantum systems." Physical Review Research 2.3 (2020): 033347) for state preparation outside of the Lindblad limit. In this protocol, a system is coupled to ancillas with a time-independent Hamiltonian, with the ancillas being periodically reset. The protocol exploits the frustration-free nature of the parent Hamiltonian, enabling the writing of local operators that map from locally excited states to locally unexcited states. The full dynamics of this protocol are simulated using Matrix Product States and quantum trajectories, and the behavior of the protocol is analyzed for different measurement intervals. In particular, our study explores the case of preparing the spin-1 Affleck-Kennedy-Lieb-Tasaki state and discusses the protocol's resilience to errors. The results show that the dynamics of the protocol match the dynamics of the Lindblad limit for relatively large measurement intervals, that the optimal measurement interval is close to the expected ideal measurement interval, and that the protocol converges even for large measurement intervals, though only slowly.

Q 8.45 Mon 16:30 Empore Lichthof

Portfolio Optimization using a Quantum Computer — •Matthias Hüls and Daniel Braun — Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Deutschland

Entering the era of Noisy Intermediate-Scale Quantum (NISQ) devices, hopes are raising to already make practical use of the existing quantum processors. While deep algorithms still fail on the error prone hardware, variational algorithms show error resilience to some extend. This makes them well suited for the NISQ technology. Therefore, popular candidates like the Quantum Approximate Optimization Algorithm (QAOA), designed to solve combinatorial optimization problems, attracted much attention in recent years. In a case study, we benchmark the performance of the QAOA for the portfolio optmimization problem. We focus on how the characteristics of a given problem instance influence the algorithms performance and deduce a criterion for distinguishing between 'easy' and 'hard' instances.

Q 8.46 Mon 16:30 Empore Lichthof

Performance of Grover's Algorithm on IBM Quantum Processors — •Yunos El Kaderi[1,2], Andreas Honecker[1], and Iryna Andriyanova[2] — [1]LPTM UMR CNRS 8089, CY Cergy Paris Université, France — [2]ETIS UMR CNRS 8051, CY Cergy Paris Université, France

This work tests the performance of Grover search circuits on the available IBM superconducting quantum devices that are accessible on the IBMQ cloud. Ideally, we expect to get a probability distribution that is clearly peaked at the targeted state. However, the quantum circuit executed on NISQ devices is vulnerable to noise which leads to fluctuations in the expected results. This depends on the quality of the device which is defined by a Quantum Volume parameter and on the depth of the circuit. Some previous works reached results that are completely noisy with no useful information, see for example Ref. [1] for 4 qubits (16 elements). Here we show that suitable implementations on concurrent IBMQ devices can actually yield useful results and explore the limitations.

[1] Y. Wang, P.S. Krstic, Phys. Rev. A **102**, 042609 (2020)

Q 8.47 Mon 16:30 Empore Lichthof

QVLS Q1 supporting experiment for development of techniques for ion transport and sympathetic cooling — •Christian Joohs[1,2], Markus Duwe[1,2], Yannick Hermann[1,2], Ludwig Krinner[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig

Within the ongoing development of the ion-based quantum computer Q1 carried out by QVLS (**Q**uantum **V**alley **L**ower **S**axony), a supporting experiment is being built and used for research and development of transport and cooling techniques. The trap is experimentally realised by a surface electrode Paul trap, which allows movement of trapped ions in a two-dimensional space above the trap. This possibility is used to realise the computer in a register-like fashion (termed QCCD architecture [1,2]) by having different zones on the trap chip that account for different tasks including storage, readout, and quantum logic gate application. A key aspect therefore is the development of ion transport techniques between said zones while maintaining a low heating rate and without interruption of the ion's electronic quantum state. Furthermore, we study the possibility to sympathetically cool two logic ions with a single cooling ion of significantly heavier mass. We report on previous progress and goals.

[1] D.J. Wineland *et al.*, J. Res. Natl. Inst. Stand. Technol. **103**, 259 (1998)

[2] D. Kielpinski, C. Monroe, and D. J. Wineland, Nature **417**, 709 (2002)

Q 8.48 Mon 16:30 Empore Lichthof

Towards a fault tolerant microwave-driven two qubit quantum processor — •Markus Duwe[1,2], Hardik Mendpara[1,2], Nicolas Pulido-Mateo[1,2], Ludwig Krinner[1,2], Giorgio Zarantonello[3], Amado Bautista-Salvador[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]National Institute of Standards and Technology, Boulder, USA

A universal quantum gate set can be realized by the combination of single-qubit gates and one entangling operation. In this work, we realize such a gate set using the microwave near field approach [1]. We trap two 9Be+ ions in a radio-frequency surface electrode trap and perform the quantum logic operations with embedded microwave conductors. The individual qubits are addressed by micromotion sidebands [2] and the entangling gate is performed via a Mølmer-Sørensen type interaction. We approach an infidelity of 10^{-4} with single qubit gates and 10^{-3} with entangling gates using partial tomography [3]. We report on challenges and solutions for further improving the gate fidelities and to characterize gate errors.

[1] C. Ospelkaus *et al.*, Phys. Rev. Lett. **9**, 090502 (2008)
[2] U. Warring *et al.*, Phys. Rev. Lett. **17**, 173002 (2013)
[3] M. Duwe *et al.*, Quantum Sci. Technol. **7**, 045005 (2022)

Q 8.49 Mon 16:30 Empore Lichthof

Next generation platform for implementing fast gates in ion trap quantum computation — •Donovan Webb, Sebastian Saner, Oana Bazavan, Mariella Minder, and Christopher Ballance — University of Oxford

Scalable trapped-ion quantum computation relies on the development of high-fidelity fast entangling gates in a many ion crystal. Conventional geometric phase gates either suffer from scattering errors or off-resonant carrier excitations. A potential route to achieve fast entanglement is creating a standing wave which can suppress the unwanted carrier coupling [Mundt 2003].

We present the roadmap to our next-generation platform tailored for fast gates in the ~1μs regime where gate speeds become comparable to the secular trap frequency. The quadrupole transitions between S1/2 and D5/2 levels in Calcium 40 will be driven to perform Molmer-Sorenson gates with a standing wave rather than a typical travelling wave. The off-resonant carrier excitation may be strongly suppressed by placing ions at the nodes of the optical lattice. This new platform has scope for a multi-ion chain and a corresponding array of optical lattices which each address a single ion. The lattice array is created by a set of counter-propagating beams which are tightly focused by a symmetric setup of high-NA lenses. Control of the optical phase at the ion site will be achieved by actively stabilising the counter-propagating beam interferometer and feedbacking on the ion signal.

Q 9: Quantum Gases: Bosons I

Time: Monday 17:00–19:00 Location: A320

Invited Talk Q 9.1 Mon 17:00 A320

Compressibility and the equation of state of an optical quantum gas in a box — •Julian Schmitt — University of Bonn, Germany

Quantum gases of atoms, exciton-polaritons, and photons provide a test bed for many-body physics under both in- and out-of-equilibrium settings. Experimental control over their dimensionality, potential energy landscapes, or the coupling to reservoirs offers wide possibilities to explore phases of matter, for example, by probing susceptibilities, as the compressibility. For gases of material particles, such studies of the mechanical response are well established, in fields from classical thermodynamics to cold atomic quantum gases; for optical quantum gases, they have so far remained elusive. In my talk, I will discuss experimental work demonstrating a measurement of the compressibility of a two-dimensional quantum gas of photons in a box potential, from which we obtain the equation of state for the optical medium. The experiment is carried out in a nanostructured dye-filled optical microcavity. We observe signatures of Bose-Einstein condensation at large phase-space densities in the finite-size system. Upon entering the quantum degenerate regime, the density response to an external force sharply increases, hinting at the peculiar prediction of a highly compressible Bose gas. In other recent work, we have demonstrated a non-Hermitian phase transition of an open photon Bose-Einstein condensate, which is revealed by an exceptional point in the fluctuation dynamics.

Q 9.2 Mon 17:30 A320

Realization of a fractional quantum Hall state with ultracold atoms — •Julian Léonard[1,2], Sooshin Kim[1], Joyce Kwan[1], Perrin Segura[1], Fabian Grusdt[3,4], Cécile Repellin[5], Nathan Goldman[6], and Markus Greiner[1] — [1]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna, Austria — [3]Department of Physics and ASC, LMU München, Theresienstr. 37, München D-80333, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany — [5]Univ. Grenoble Alpes, CNRS, LPMMC, 38000 Grenoble, France — [6]CENOLI, Université Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium

Fractional quantum Hall states embody emblematic instances of strongly correlated topological matter, where the interplay of magnetic fields and interactions gives rise to exotic properties including fractionally charged quasi-particles, long-ranged entanglement, and anyonic exchange statistics. Here, we report on the realization of a fractional quantum Hall (FQH) state with ultra-cold atoms in an optical lattice. The state is a lattice version of a bosonic $\nu = 1/2$ Laughlin state with two particles on sixteen sites. We observe a suppression of two-body interactions, we find a distinctive vortex structure in the density correlations, and we measure a fractional Hall conductivity of $\sigma H/\sigma 0 = 0.6(2)$ via the bulk response to a magnetic perturbation. Our work provides a starting point for exploring highly entangled topological matter with ultracold atoms.

Q 9.3 Mon 17:45 A320

Observation of a continous time crystal — •Hans Kessler[1], Phatthamon Kongkhambut[1], Jim Skulte[1], Evgenii Gadylshin[1], Ludwig Mathey[1], Jayson G. Cosme[2], and Andreas Hemmerich[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

Time crystals are classified as discrete or continuous depending on whether they spontaneously break discrete or continuous time translation symmetry. While discrete time crystals have been extensively studied in periodically driven systems since their recent discovery, the experimental realisation of a continuous time crystal [1] is still pending. We report the observation of a limit cycle phase in a continuously pumped dissipative atom-cavity system [2], which is characterized by emergent oscillations in the intracavity photon number. We observe that the phase of this oscillation is random for different realisations, and hence this dynamical many-body state breaks continuous time translation symmetry spontaneously. The observed robustness of the limit cycles against temporal perturbations confirms the realisation of a continuous time crystal.

[1] H. Keßler et al., Emergent limit cycles and time crystal dynamics in an atom-cavity system, PRA, 99(5), 053605 (2019)

[2] P. Kongkhambut et al., Observation of a continuous time crystal, Science 307, 6606, 670-673 (2022)

Q 9.4 Mon 18:00 A320

Dynamics of Stripe Patterns in Supersolid Spin–Orbit-Coupled Bose Gases — •Kevin T. Geier[1,2], Giovanni I. Martone[3], Philipp Hauke[1,2], Wolfgang Ketterle[4,5], and Sandro Stringari[1] — [1]Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Università di Trento, I-38123 Trento, Italy — [2]INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, Trento, Italy — [3]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-PSL Research University, Collège de France; 4 Place Jussieu, 75005 Paris, France — [4]MIT-Harvard Center for Ultracold Atoms, Cambridge, Massachusetts 02138, USA — [5]Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

The supersolid phase of matter combines superfluid properties with a crystalline spatial structure, arising as a consequence of the spontaneous breaking of both phase and translational symmetry. In spin–orbit-coupled Bose–Einstein condensates, supersolidity has been predicted and observed in the form of stripes in the density profile, but up to now it has been unclear whether the stripe pattern features the typical excitations of a crystal. In this talk, I will explain based on analytical and numerical results how spin perturbations can induce the translational, compressional, as well as rotational motion of the stripes. Our findings expose the rich hybridization of density and spin degrees of freedom and show that this system is indeed a paradigmatic supersolid with a fully dynamic crystalline structure.

Q 9.5 Mon 18:15 A320

Observation of many-body scarring in a Bose-Hubbard quantum simulator — Guo-Xian Su[1], Hui Sun[1], •Ana Hudomal[2], Jean-Yves Desaules[3], Zhao-Yu Zhou[1], Bing Yang[4], Jad C. Halimeh[5], Zhen-Sheng Yuan[6], Zlatko Papić[3], and Jian-Wei Pan[6] — [1]Heidelberg University, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]University of Leeds, UK — [4]Southern University of Science and Technology, China — [5]LMU Munich, Germany — [6]University of Science and Technology of China

Quantum many-body scarring has recently opened a window into novel mechanisms for delaying the onset of thermalization by preparing the system in special initial states, such as the $\mathbb{Z}_2$ state in a Rydberg atom system. Here we realize many-body scarring in a Bose-Hubbard quantum simulator from previously unknown initial conditions such as the unit-filling state [1]. Our measurements of entanglement entropy illustrate that scarring traps the many-body system in a low-entropy subspace. Further, we develop a quantum interference protocol to probe unequal-time correlations, and demonstrate the system's return to the vicinity of the initial state by measuring single-site fidelity. Our work makes the resource of scarring accessible to a broad class of ultracold-atom experiments.

[1] G.-X. Su et al., arXiv:2201.00821 (2022).

Q 9.6 Mon 18:30 A320

Quantum Gas Microscopy of Cesium Atoms in Optical Superlattices — Julian Wienand[1,2,3], Alexander Impertro[1,2,3], Simon Karch[1,2,3], Hendrik von Raven[1,2,3], •Scott Hubele[1,2,3], Sophie Häfele[1,2,3], Ignacio Pérez[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Schellingstr. 4, D-80799 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80333 Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, D-85748 Garching, Germany

Ultracold cesium atoms provide a promising experimental platform for quantum simulation of interacting quantum many-body phases. This is due to a convenient control of the scattering length via a broad low-field Feshbach resonance and the possibility to engineer state-dependent lattices with minimal heating. In this talk we present recent progress on our cesium quantum gas microscope, where we have implemented 2d optical superlattices, a digital mirror device (DMD) for potential shaping, and an active magnetic field stabilization. This paves the way for quantum simulation of a large variety of different Hamiltonians ranging from tunable spin models to topological lattices. In order to enhance the nearest-neighbor tunnel coupling, we work with rather short-spaced optical lattices prohibiting the direct resolution of neighboring lattice sites. To overcome this challenge we have developed a novel deep-learning assisted single-site reconstruction algorithm, which provides access to local observables.

Q 9.7 Mon 18:45 A320

Phase Diagram Detection via Gaussian Fitting of Number Probability Distribution — Daniele Contessi[1,2,3], Alessio Recati[1], and •Matteo Rizzi[2,3] — [1]Università di Trento & INO-CNR Pitaevskii BEC Center, Povo, Italy — [2]Peter-Grünberg-Institut 8, FZ Jülich, Germany — [3]Institute for Theoretical Physics, University of Cologne, Germany

In recent years, methods for automatic recognition of phase diagrams of quantum systems have gained large interest in the community: Among others, machine learning analysis of the entanglement spectrum has proven to be a promising route. Here, we discuss the possibility of using an experimentally readily accessible proxy, namely the number probability distribution that characterizes sub-portions of a quantum many-body system with globally conserved number of particles. We put forward a linear fitting protocol capable of mapping out the ground-state phase diagram of the rich one-dimensional extended Bose-Hubbard model: The results are quantitatively comparable with more sophisticated traditional numerical and machine learning techniques. We argue that the studied quantity should be considered among the most informative and accessible bipartite properties.

D. Contessi, A. Recati, M. Rizzi, https://arxiv.org/abs/2207.01478

Q 10: Photonics I

Time: Monday 17:00–19:00 Location: E001

Invited Talk Q 10.1 Mon 17:00 E001

Maiman's ruby laser reborn as diode pumped cw laser — •Walter Luhs[1] and Bernd Wellegehausen[2] — [1]Photonic Engineering Office, Herbert-Hellmann-Allee 57, 79189 Bad Krozingen, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

In ninety sixty Theodore Maiman realized the first laser, a flashlamp pumped Ruby laser, which was the onset of a tremendous ongoing development of optics and quantum optics.

In the growing family of lasers, the Ruby laser however remained exotic, needing a population inversion with respect to the ground state. Although possible, cw operation was extremely difficult to achieve, and so the Ruby laser only found applications as a powerful pulsed system.

In 2019, we could first demonstrate cw laser oscillation of ruby in linear and ring resonators, pumped with 1 W 405 nm laser diodes, and achieve with Ruby crystals of 5 mm length stunningly low thresholds of below 100 mW and output powers up to 80 mW. Some of the ruby crystals used in this work can be traced back to the original material from Theodore Maiman, handed by himself to Herbert Welling, the German laser pioneer, for first experiments and then remained for more than 50 years in the basement of the institute.

Meanwhile, we realized ultra-compact and stable laser systems with resonators below 3 mm length, yielding narrowband tunable single frequency emission. Features of these systems are presented, and possible applications will be discussed.

Q 10.2 Mon 17:30 E001

Generation of ultrashort VUV pulses by frequency-tripling compressed high-energy pulses centered around 400 nm — •Nora Schmitt, Armin Azima, Marek Wieland, Mark Prandolini, and Markus Drescher — University of Hamburg, Institute for Experimental Physics, 22761 Hamburg, Germany

Generating ultrashort laser pulses in the vacuum ultraviolet spectral region (VUV, ∼100 to 200 nm) is key to studying an abundance of atomic and molecular transitions. Pump-probe experiments utilizing intense ultrashort laser pulses in this spectral region have successfully been realized and used to study the dynamics of several systems. However, the most widely used source in the VUV is the 5th harmonic of a Ti:Sa laser, which is centered around 160 nm, limiting the number of accessible transitions. In order to drive nonlinear transitions in this wavelength regime, alternative VUV generation schemes should provide pulse energies approaching μJ levels . In a novel approach, we generate pulses around 133 nm by frequency-tripling in a gas cell. The fundamental pulses, centered at 400 nm, are spectrally broadened in a stretched hollow core capillary fiber filled with helium and temporally compressed by a slightly detuned 4f-setup. For the 400 nm pulses, we obtain a pulse duration of 10 fs (FWHM) at 800 μJ pulse energy, evaluated by fringe resolved interferometric autocorrelation (FRIAC) measurements. Our simulations suggest that tripling these pulses in our geometry will yield a conversion efficiency in the order of 10^{-3}.

Q 10.3 Mon 17:45 E001

Tailored transverse field distributions in an enhancement resonator for high harmonic generation — •Tamila Rozibakieva[1], Stephan H. Wissenberg[2], Hans-Dieter Hoffmann[2], Constantin L. Häfner[2,3], Peter G. Thirolf[1], and Johannes Weitenberg[2,4] — [1]Ludwig-Maximilians-Universität München LMU — [2]Fraunhofer Institute for Laser Technology ILT — [3]Chair for Laser Technology LLT, RWTH Aachen University — [4]Max-Planck Institute of Quantum Optics MPQ

An enhancement resonator is a passive optical resonator, which is used for resonant enhancement of an optical power or intensity. Enhancement resonators are used in nonlinear processes such as high-harmonic generation (HHG), which requires high intensity (>10^13 W/cm^2) even at large repetition rates (>10 MHz). At Fraunhofer ILT, a VUV frequency comb is being set up for the excitation of the low-energy isomeric nuclear transition of 229-Thorium at LMU Munich as part of an ERC synergy project. The spectrum in the VUV frequency comb can be achieved via HHG in a Xe gas jet, in our case as the 7th harmonic of a driving laser at 1050 nm. A key challenge with enhancement resonators for HHG is the coupling of the harmonics out of the resonator. The talk will focus on an analysis of transverse modes that can be used to geometrically couple out high harmonics through a slit in a resonator mirror, for example the GH[1,0]-mode, the slit mode or a non-collinear resonator. It will be presented how a large spatial overlap with impinging Gaussian beam can be achieved for these modes. Funding: ERC Synergy project, Grant Agreement No. 856415.

Q 10.4 Mon 18:00 E001

Femtosecond Fast Tunable Ultraviolet Radiation through Non-collinear Sum-frequency Mixing in a Visible NOPO — •Fridolin Geesmann[1], Robin Mevert[1,2], David Zuber[1,2], Han Rao[1,2], and Uwe Morgner[1,2,3] — [1]Institute of Quantum Optics, Leibniz Universität Hannover, Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Disciplines), Hannover, Germany — [3]Laser Zentrum Hannover e.V., Hannover, Germany

We report on a rapidly tunable non-collinear optical parametric oscillator (NOPO), which simultaneously delivers femtosecond pulses in the visible and ultraviolet wavelength range. The system is pumped by the third harmonic of a Yb based MOFA system, which is focused into a BBO crystal to generate the visible pulses via a DFG process. A KDP crystal is placed in a second focus of the NOPOs ring cavity for further frequency conversion. Thereby, ultraviolet wavelengths were reached through non-collinear sum-frequency mixing of the visible pulses with residual infrared pump radiation. With this approach, two synchronized outputs were realized, delivering fast tunable pulses from 449-690 nm and 340-413 nm with output powers up to 232 mW and 59 mW, respectively. By replacing the visible output coupler with an HR mirror, even higher power in the UV of up to 90 mW was achieved. In addition, the quick tuning of the two outputs was shown over their entire wavelength range with a frequency of 43.9 Hz. Even higher tuning speeds can be expected by using a different piezoelectric actuator, as this has been the limiting factor so far.

Q 10.5 Mon 18:15 E001

Towards intracavity optical parametric amplification of a Ti:sapphire laser oscillator — •Robin Mevert[1,2], Jintao Fan[1,2], Fridolin Jakob Geesmann[1,2], Han Rao[1,2], David Zuber[1,2], Tino Lang[3], and Uwe Morgner[1,2,4] — [1]Leibniz Universität Hannover, Institute of Quantum Optics, Hannover, Germany — [2]Leibniz Universität Hannover, Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Disciplines), Hannover, Germany — [3]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germ — [4]Laser Zentrum Hannover e.V., Hannover, Germany

Nowadays, Ti:sapphire oscillators still play a major role as a typical work horse for the generation of femtosecond laser pulses in the near-infrared since its broadband emission range can support pulse durations in the sub-10fs range. Unfortunately, power scaling of Ti:sapphire lasers is limited by the thermal lensing effect inside the Ti:sapphire crystal as well as the additional gain-narrowing effects. On the other hand, synchronously-pumped femtosecond optical parametric oscillators (OPOs) in the near-infrared are easily power scalable since there are only nonlinear absorption effects inside the gain material. This fact is utilized nowadays in optical parametric amplifiers which are often used to amplify the output power of a Ti:Sapphire laser. However, the main drawback is the drastic decrease in repetition rate towards the kHz range which causes additional obstacles for later applications such as high-harmonic generation. In this work, we investigate the possibility to use the parametric gain of a BBO-crystal to amplify the Ti:sapphire laser inside a single cavity.

Q 10.6 Mon 18:30 E001

Jitter comparison of gain-switched diodes — •Simon Angstenberger, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

Gain-switched diodes are a cost-efficient and widely used approach to seed flexible amplifier chains. However, the timing jitter of the gain-switching process limits the implementation in applications with critical timing on the tens of picosecond scale. We compare different diode concepts, namely a Fabry-Perot (FP) laser diode and a distributed feedback (DFB) laser diode. We find that the timing jitter for the FP diode is significantly lower, when driven with the same electronic driver. Furthermore, we investigate the influence of optical feedback by means of a fiber Bragg grating (FBG) on the jitter performance. Eventually, a comparison is made of the obtained values to a fiber laser for reference.

Q 10.7 Mon 18:45 E001

Optimization of photonic multilayer structures to increase upconversion efficiency — •Fabian Spallek[1,2], Stefan Yoshi Buhmann[2], Thomas Wellens[1], and Andreas Buchleitner[1,3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [2]Institut für Physik, Universität Kassel — [3]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg

The efficiency of solar silicon solar cells can be substantially improved by widening the spectral operating window by means of upconversion materials [1]. These convert two low-energy photons into one photon with higher energy [1]. Embedding the upconverter material in photonic dielectric nanostructures allows to influence the interplay of absorption and emission rates, energy transfer processes, local irradiance and local density of (photonic) states which in turn determines the overall efficiency.

We utilize methods from macroscopic quantum electrodynamics to calculate the influence of multilayer nanostructures on spontaneous emission and absorption rates in the upconverter. This allows us to propose specific designs optimized for upconversion efficiency [2]. Lastly, we take into account manufacturing errors and compare indicators for the achievable upconversion luminescence and quantum yield of our optimized design to existing, experimentally implemented Bragg structures.

[1] C. L. M. Hofmann et al., Nat. Commun. **12**, 14895 (2021)
[2] F. Spallek et al., J. Phys. B: At. Mol. Opt. Phys. **50**, 214005 (2017)

Q 11: Precision Measurements: Gravity I

Time: Monday 17:00–19:00 Location: E214

Q 11.1 Mon 17:00 E214

a testbed for Tilt-To-Length coupling and Differential-Wavefront-Sensing performance in LISA — •Alvise Pizzella, Miguel Dovale, and Gerhard Heinzel — AEI Hannover, Germany

The LISA mission aims at measuring gravitational waves (GWs) in the sub-Hz band using inter-spacecraft interferometry. It consists in a constellation of three satellites in triangle formation with 2.5 Gm-long arms following an Earth-like heliocentric orbit. The target sensitivity of pm/Hz^1/2 presents unprecedented technical challenges; such as minimal detected power levels, causing shot noise, and the coupling of the angular jitter of the spacecraft and test masses to the interferometrically-measured longitudinal displacement (Tilt-To-Length (TTL) coupling). TTL is forecasted to be the second highest noise entry in LISA. In order to readout from the heterodyne interference beatnote the length and angular signals, necessary for respectively GWs detection and maintaining the interferometer*s alignment, LISA implements Differential-Wavefront-Sensing (DWS), combining the individual phase readouts from the four segments of a Quadrature PhotoDiode (QPD). An ultra stable interferometer testbed representative of the Optical Bench (OB) of a LISA spacecraft has been developed in order to validate the critical interferometric techniques for LISA. The testbed features steering mirrors that can induce synthetic tilts between the beams to simulate spacecraft or test mass motion. This experiment has been used to demonstrate optical reduction of TTL by using imaging. Current work is focusing on developing a new method to readout the DWS and achieving nrad DWS noise levels.

Q 11.2 Mon 17:15 E214

Dual balanced readout for scattered light noise suppression in gravitational wave detection — •André Lohde, Daniel Voigt, and Oliver Gerberding — Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany

Gravitational wave interferometers are highly sensitive to scattered light noise. This is due to the interfering character of straylight backscattered into the interferometer that is potentially modulated at moving surfaces. Today's interferometers, such as LIGO, Virgo and KAGRA are already limited by scattered light noise in the low frequency domain. Future detectors, however, such as the Einstein Telescope, depend upon advanced scattered light mitigation to fulfill design requirements.

Here, I present the technique of implementing two balanced homodyne detectors for the readout of a Michelson interferometer. This technique promises to allow partial subtraction of scattered light noise by simple arithmetic operations and thus improval of the sensitivity of gravitational wave detectors.

Q 11.3 Mon 17:30 E214

A Free-Beam Backlink for the Space-Based Gravitational Wave Detector LISA — •Daniel Jestrabek[1,2], Lea Bischof[1,2], Melanie Ast[1,2], Jiang Ji Ho Zhang[1,2], and Gerhard Heinzel[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Hannover, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

The Laser Interferometer Space Antenna (LISA) will be the first Gravitational Wave Detector in space, consisting of three satellites forming an equilateral triangle of 2.5 million kilometers distance. The challenge introduced by the relative movements of the satellites can be overcome by the implementation of steerable optical benches to compensate for these changes. This makes an optical connection necessary that links the moving benches so that the gravitational wave signal can be extracted in post-processing. One possible solution for such an optical connection (also called "Backlink") is the use of mirrors that guide the light in free space between the benches. The mirrors must be actively steered to keep this Free-Beam Backlink stable. Control electronics were developed, tested, and implemented for the Free-Beam Backlink within a LISA-like test bed, the Three-Backlink Experiment. This test bed consists of two separate, rotatable benches in between which light is exchanged through three optical connections: the free-beam link and two fiber-based solutions.

We present here the working principle of the Free-Beam Backlink and its optimization, enabling stable heterodyne interference over separated optical benches with a low noise contribution.

Q 11.4 Mon 17:45 E214

Compact Laser Interferometer for Testmass Readout in Gravitational Wave Detectors — •Wanda Vossius, Meenakshi Mahesh, Tobias Eckhardt, Leander Göbbels, and Oliver Gerberding — Institut für Experimentalphysik, Geb. 68 Z. 21-21c, Luruper Chaussee 149, 22761 Hamburg, Deutschland

In order to realise the sensitivity required for future gravitational wave detectors, there is a need for an increase of three orders of magnitude for the precision of the testmass readout. This would decrease the noise at frequencies below 10Hz and allow for the detection of gravitational waves of lower amplitude. Local displacement sensors in gravitational wave detectors have to be both compact and stable without the need for readjustment while the detector is running.

We present the plan and current status on a compact readout sensor in the form of an interferometer. This interferometer is only 3 cm long with an armlength of about 5 cm. It contains a single quasimonolithic optic which results in an unequal armlength Michelson interferometer with a dual port readout. In order to reduce the coupling of electronic noise and ghostbeams into the readout, we plan to use a Deep Frequency Modulation on the laser. To ensure the stability criteria, the optical components will be glued onto a titanium carrier.

Q 11.5 Mon 18:00 E214

Postprocessing subtraction of tilt-to-length noise in LISA — •Sarah Paczkowski[1,2], Roberta Giusteri[1,2], Martin Hewitson[1,2], Nikolaos Karnesis[3], Ewan Fitzsimons[4], Gudrun Wanner[1,2], and Gerhard Heinzel[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany — [2]Leibniz Universität Hannover, D-30167 Hannover, Germany — [3]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece — [4]The UK Astronomy Technology Centre, Royal Observatory, Edinburgh, Blackford Hill, Edinburgh EH9 3HJ, United Kingdom

The space mission LISA aims to observe gravitational waves over a frequency range from 0.1 mHz to 1 Hz. LISA is characterised by its three satellites which form a nearly equilateral triangle with a 2.5 million km arm length. Laser interferometers will measure the distance between free-falling test masses hosted in each satellite with picometer precision down to mHz frequencies. To reach this performance, several noise sources have to be kept under control.

One of these is the coupling of an angular jitter into the interferometric phase readout, called TTL coupling. This cross-coupling arises, for example, from misalignments within the optical system. Unless mitigated, this noise source is expected to affect the scientific performance of LISA. In this talk, I will present a method to calibrate and subtract TTL noise that has no impact on LISA science operations. Selected proof-of-principle simulation results will demonstrate the performance based on the current design configuration of LISA.

Q 11.6 Mon 18:15 E214

Status of the AEI 10m Prototype: a gravitational wave detector prototyping facility — Matteo Carlassara[1,2], Firoz Khan[1,2], Philip Koch[1,2], Johannes Lehmann[1,2], Harald Lück[1,2], Juliane von Wrangel[1,2], Janis Wöhler[1,2], and •David S. Wu[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany — [2]Leibniz Universität Hannover, D-30167 Hannover, Germany

The current status will be presented on the Albert Einstein Institute (AEI) 10 m Prototype facility in Hannover, where new technologies and techniques for full scale gravitational wave detectors (GWDs) are developed and tested. A particular area of focus is the investigation of techniques to surpass the standard quantum limit (SQL) of interferometry by providing a test bed interferometer to experimentally test these techniques in a low noise GWD-like environment. Current activities are focussed on getting the Sub-SQL Interferometer online and commissioned to it's designed sensitivity. These activities range from new motion sensors, seismic isolation techniques, precision optics, and scattered light mitigation.

Q 11.7 Mon 18:30 E214

Toward testing LISA post-processing pipeline under realistic circumstances with experimental data. — •Narjiss Messied — Max-Planck Institut für Gravitationsphysik (Albert-Einstein Institut), Callinstraße 38, 30167 Hannover, Germany

Laser Interferometer Space Antenna (LISA) is a space-based mission that aims to detect gravitational waves in the mHz range with heterodyne interferometry. Gravitational wave signals encoded in a beam phase are extracted by a phasemeter. Raw phase data from this core device is dominated by various noise sources, for example, laser frequency noise, clock noise, etc. Hence, LISA requires the initial noise reduction pipeline (INReP), a set of complex data post-processing algorithms, in order to dig up gravitational wave signals from such noise-dominant data. Any research on this pipeline has relied on synthetic data produced by numerical LISA simulators so far, which can not cover all realistic features of actual phasemeter outputs during the mission. In this talk, we present the latest efforts toward the verification of this pipeline with experimental data from our on-ground testbed called the Hexagon, which acts as a miniature-scale LISA with three beam sources and three independent phasemeters.

Q 11.8 Mon 18:45 E214

The Three-Backlink Experiment for the first space-based gravitational wave detector LISA — •Jiang Ji Ho Zhang[1,2], Lea Bischof[1,2], Daniel Jestrabek[1,2], Melanie Ast[1,2], Michael Born[1,2], Katharina-Sophie Isleif[3], Stefan Ast[4], Nicole Knust[1,2], Daniel Penkert[1,2], and Gerhard Heinzel[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Hannover, Germany — [2]Leibniz Universität Hannover, Hannover, Germany — [3]Deutsches Elektronen-Synchroton (DESY) Zeuthen, Hamburg, Germany — [4]DLR-Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

The Laser Interferometer Space Antenna (LISA) will be the first gravitational wave detector in space, aiming to use laser interferometry to detect gravitational wave signals in the 0.1 mHz to 1 Hz band. It consists of three satellites forming a near-equilateral triangle with 2.5 million km arms. Due to the orbital mechanics, the inter-satellite distances and angles vary by about 1% and 1.5% per year, respectively. Each satellite features two moving optical sub-assemblies (MOSAs) that compensate for the angular dynamics. They both carry one optical bench, which in turn are connected via a flexible optical link. This is the so-called Backlink. The noise of the optical pathlength difference between two counter propagating beams along the Backlink is required to reach 1 pm/sqrt(Hz) stability. The Three-Backlink Experiment is a trade-off study between different designs of the Backlink: two fiber-based and one free beam. Here, we report on the design and technical aspects of the experiment, the current status and the ongoing work.

Q 12: Precision Spectroscopy of Atoms and Ions I (joint session A/Q)

Time: Monday 17:00–18:45 Location: F107

Invited Talk Q 12.1 Mon 17:00 F107

Nonperturbative dynamics in heavy-ion-atom collisions — •Pierre-Michel Hillenbrand[1], Siegbert Hagmann[2], Alexandre Gumberidze[2], Yury Litvinov[2,3], and Thomas Stöhlker[2,4,5] — [1]Justus-Liebig-Univ., Giessen — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [3]Ruprecht-Karls-Univ., Heidelberg — [4]Helmholtzinstitut Jena — [5]Friedrich-Schiller-Univ., Jena

Experimental data for atomic collisions of highly-charged ions are essential for benchmarking the theoretical description of dynamical processes in atomic physics. Of particular challenge is the accurate description of those processes that exceed the applicability of relativistic first-order perturbation theories. Recently, we have investigated two characteristic cases of such collision systems at the GSI heavy-ion accelerator. For collisions of U^{89+} projectiles with N_2 and Xe targets at 76 MeV/u, we studied the electron-loss-to-continuum cusp both experimentally and theoretically. We compared the continuum electron spectra of the two collision systems, which originate from the ionization of the projectile, and were able to identify a clear signature for the non-perturbative character of the collision systems [1]. Furthermore, we performed an x-ray spectroscopy experiment for slow collisions of Xe^{54+} and Xe^{53+} projectiles with a Xe target at 30 and 15 MeV/u. We analyzed the target $K\alpha$ satellite and hypersatellite lines to derive cross section ratios for double-to-single target K-shell vacancy production and compared the results to relativistic two-center calculations [2].

[1] Phys. Rev. A **104**, 012809 (2021)
[2] Phys. Rev. A **105**, 022810 (2022)

Q 12.2 Mon 17:30 F107

High-precision hyperfine structure measurement of $^9Be^{3+}$ for tests of nuclear shielding theory — •Stefan Dickopf, Annabelle Kaiser, Marius Müller, Bastian Sikora, Zoltan Harman, Christoph Keitel, Stefan Ulmer, Andreas Mooser, and Klaus Blaum — Max-Planck Institute for Nuclear Physics, Heidelberg, Germany

Hyperfine structure (HFS) measurements on $^3He^{1+}$ in our Penning-trap setup have recently been used to determine the magnetic moment of its nucleus [1]. To use this value for high accuracy magnetic field measurements with ^{3}He-NMR-probes it has to be corrected for by a diamagnetic shielding due to the orbiting electrons. By measuring the HFS of $^9Be^{3+}$ and comparing it to measurements on $^9Be^{1+}$ we can test the theory of the diamagnetic shielding factor [2,3].

A determination of the g-factor of the nucleus with a precision of about 10^{-9} is planned, making a test of the diamagnetic shielding on the same level possible. Recent improvements to our setup and a high precision mass measurement carried out at the PENTATRAP experiment will further allow us to determine the bound electron g-factor of $^9Be^{3+}$ to a few parts in 10^{-11}, yielding an additional high-precision test of QED g-factor calculations [1].

[1] A. Schneider et al, Nature 606, 878-883 (2022)
[2] D. J. Wineland, J. J. Bollinger, and Wayne M. Itano, Phys. Rev. Lett. 50, 628-631 (1983)
[3] K. Pachucki and M. Puchalski, Optics Communication 283, 641-643 (2010)

Q 12.3 Mon 17:45 F107

Hyperfine Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at Alphatrap — •C. M. König[1], F. Heisse[1], I. V. Kortunov[2], J. Morgner[1], T. Sailer[1], B. Tu[1,3], V. Vogt[2], K. Blaum[1], S. Schiller[2], and S. Sturm[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [2]Institut für Experimentalphysik, Univ. Düsseldorf, 40225 Düsseldorf — [3]Institute of Modern Physics, Fudan University, Shanghai 200433

As the simplest molecules, molecular hydrogen ions (MHI) are an excellent system for testing QED. In the Penning-trap setup Alphatrap [1] we can perform high-precision spectroscopy on single MHI using non-destructive quantum state detection. Measurements on the hyperfine structure (HFS) of HD^+, allow us to extract the bound g factors of the constituent particles, as well as coefficients of the hyperfine hamiltonian. The latter can be compared with high-precision *ab-initio* theory and are important for a better understanding of rovibrational spectroscopy performed on this ion, from which fundamental constants, such as m_p/m_e are determined to high precision [2].

We are currently extending our methods to single-ion rovibrational laser spectroscopy of MHI. The development of these techniques is one of the required steps towards spectroscopy of an antimatter $\overline{H}_2^-$ ion [3]. I will present an overview of our setup, measurement results of the HFS of HD^+ and first steps towards rovibrational laser spectroscopy.

[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425-1491 (2019)
[2] I. V. Kortunov, *et al.*, Nature Physics vol **17**, 569-573 (2021)
[3] E. Myers, Phys. Rev. A **98**, 010101(R) (2018)

Q 12.4 Mon 18:00 F107

Probing a beyond standard model force via isotope shift spectroscopy in ultracold mercury — •Thorsten Groh, Felix Affeld, and Simon Stellmer — Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany

High precision spectroscopy of atomic isotope shifts could probe for a new beyond standard model (SM) force carrier that directly couples electrons and neutrons [Delaunay, PRD 96, 093001; Berengut, PRL 120, 091801], where signatures of such new particles would emerge as nonlinearities in King plots of scaled isotope shifts on different electronic transitions.

While latest spectroscopy of Ytterbium [Hur, PRL 128, 163201; Figueroa, PRL 128, 073001; Ono, PRX 12, 021033] down to the Hz-level already show strong deviations from linearity, it is hard to distinguish new physics from many SM effects like quadratic field shift and nuclear deformations.

Mercury is one of the heaviest laser-coolable elements with a core close to the lead nuclear shell closure, which suppresses nuclear deformations. It is an ideal platform for isotope spectroscopy possessing five naturally occurring bosonic isotopes, all of which we spectroscopically address in a magneto-optical trap. Our precision isotope shift spectroscopy in ultracold mercury on a total of five optical transitions combined with multidimensional King plot analysis show strong nonlinearities. We report on our latest improvements in the measurements and on new analysis of the nonlinearity origins.

Q 12.5 Mon 18:15 F107

1s Hyperfine splitting in Muonic Hydrogen — •Siddharth Rajamohanan[1], Ahmed Ouf[1], and Randolf Pohl[2] — [1]QUANTUM, Institut für Physik & Exzellenzcluster PRISMA,Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany — [2]Institut für Physik, QUANTUM und Exzellenzcluster PRISMA+, Johannes Gutenberg-Universität Mainz,55099 Mainz, Germany

Precision measurements on atoms and ions are a powerful tool for testing bound-state QED theory and the Standard Model [1]. Experiments done in the last decade by the CREMA collaboration on muonic Hydrogen and Helium have given a more accurate understanding of the lightest nuclei charge radius [2,3]. Our present experiment aims at a measurement of ground state Hyperfine Splitting in muonic hydrogen up to a relative accuracy of 1 ppm using pulsed laser spectroscopy. This allows us to determine the Zemach radius, which encodes the magnetic properties of the proton. A unique laser system, multi-pass cavity, and scintillation detection system are necessary for the experiment. We report the current status of our experiment and the recent developments.

[1] M. S. Safronova, D. Budker, D. DeMille, Derek F. Jackson Kimball, A. Derevianko, and Charles W. Clark, Rev. Mod. Phys. 90, 025008 (2018)
[2] R. Pohl et al., Nature 466, 213 (2010)
[3] A. Antognini, et al., Science, Vol. 339, 2013, pp. 417-420

Q 12.6 Mon 18:30 F107

Ground-state hyperfine spectroscopy of $^3He^+$ in a Penning trap — •Marius Müller[1], Antonia Schneider[1], Bastian Sikora[1], Stefan Dickopf[1], Annabelle Kaiser[1], Natalia S. Oreshkina[1], Alexander Rischka[1], Igor A. Valuev[1], Stefan Ulmer[2], Jochen Walz[3,4], Zoltan Harman[1], Christoph H. Keitel[1], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, Wako, Japan — [3]Helmholtz-Institut, Mainz, Germany — [4]Johannes Gutenberg Universität, Mainz, Germany

Hyperpolarized ^3He NMR magnetometers have intrinsically smaller systematic corrections than standard water NMR probes [1]. Therefore, they are an excellent candidate for high-precision absolute magnetometry in several experiments such as the muon g-2 experiments.

We measured the four ground-state hyperfine transition frequencies of a single $^3He^+$ ion, stored in the 5.7 T magnetic field of our cryogenic double Penning trap setup. From the spin-flip resonances the electronic and nuclear g-factors g_e and g_I, the zero-field hyperfine splitting E_{hfs}, as well as the Zemach radius r_Z were extracted with a relative precision of 220 ppt, 810 ppt, 30 ppt and 0.9 %, respectively [2]. This constitutes a direct calibration of ^3He NMR probes and an improvement of the precision by one order of magnitude compared to previous indirect measurements of the nuclear magnetic moment.

[1] Farooq et al., Phys. Rev. Lett. 124, 223001 (2020)
[2] Schneider et al., Nature 606, 878-883 (2022)

Q 13: Ultra-cold Atoms, Ions and BEC I (joint session A/Q)

Time: Monday 17:00–19:00 Location: F303

Invited Talk Q 13.1 Mon 17:00 F303

Multi-frequency optical lattice for dynamic lattice-geometry control — Marcel Kosch[1], •Luca Asteria[1,2], Henrik Zahn[1], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut für Laserphysik, Hamburg University — [2]The Hamburg Centre for Ultrafast Imaging — [3]Zentrum für Optische Quantentechnologien, Hamburg

Ultracold atoms in optical lattices are pristine model systems with a tunability and flexibility that goes beyond solid-state analogies. However, a fast change of the lattice geometry remains intrinsically difficult. Here we introduce a multi-frequency lattice for fast and flexible lattice-geometry control and demonstrate it for a three-beam lattice, realizing the full dynamical tunability between honeycomb lattice, boron-nitride lattice and triangular lattice on the microsecond scale, i.e., fast compared to the relevant energy scales. At the same time, the scheme ensures intrinsically high stability of the lattice geometry. We introduce the concept of a geometry phase as the parameter that fully controls the geometry and observe its signature as a staggered flux in a momentum space lattice. Tuning the geometry phase allows to dynamically control the sublattice offset in the boron-nitride lattice. We use a fast sweep of the offset to transfer atoms into higher Bloch bands, and perform a new type of Bloch band spectroscopy by modulating the sublattice offset. Finally, we generalize the geometry phase concept and the multi-frequency lattice to 3D optical lattices and quasi-periodic potentials. This scheme will allow novel Floquet and quench protocols to create and probe, e.g., topological properties.

Q 13.2 Mon 17:30 F303

Sturdy and Compact Laser System for Cold Atom Experiments in BECCAL on the ISS — •Tim Kroh[1,2], Victoria Henderson[1,2], Jakob Pohl[1,2], Matthias Schoch[1], Christoph Weise[1], Hrudya Thaivalappil Sunilkumar[1], Hamish Beck[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Jean Pierre Marburger[3], Faruk Alexander Sellami[3], Esther del Pino Rosendo[3], André Wenzlawski[3], Matthias Dammasch[2], Ahmad Bawamia[2], Andreas Wicht[2], Patrick Windpassinger[3], Achim Peters[1,2], and the BECCAL Team[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]DLR-SC — [5]DLR-SI — [6]DLR-QT — [7]IQ & IMS, LUH — [8]ILP, UHH — [9]ZARM, Bremen — [10]IQO, UULM

BECCAL (Bose-Einstein Condensate–Cold Atom Laboratory), a multi-user facility designed for operation on the ISS, is a DLR and NASA collaboration built on the heritage of NASA's CAL, sounding rocket and drop tower experiments. Fundamental physics will be explored with Rb and K BECs and ultra-cold atoms in microgravity, at longer time- and ultra-low energy scales compared to those achieved on earth. The laser system design provides a reliable and robust combination of micro-integrated diode lasers (from FBH) and miniaturized free-space optics on Zerodur boards (from JGU), interconnected with fiber optics, to meet the unique challenge of matching the complexity of the required light fields to the stringent size, weight, and power limitations on the ISS. An update one the BECCAL laser system design will be given based on the requirements, concepts, and heritage which formed it. Funding by DLR / BMWK grant numbers 50 WP 2102, 2103, 2104.

Q 13.3 Mon 17:45 F303

Observation of vortices and vortex stripes in a dipolar BEC of Dysprosium — •Lauritz Klaus[1,2], Thomas Bland[1,2], Elena Poli[2], Claudia Politi[1,2], Giacomo Lamporesi[3], Eva Casotti[1,2], Russell Bisset[2], Manfred Mark[1,2], and Francesca Ferlaino[1,2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [2]Institut für Experimentalphysik, Universität Innsbruck, Austria — [3]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, Italy

Quantized vortices are a defining feature of superfluid systems under rotation and have been extensively investigated in ultracold atom experiments with isotropic contact interactions. However, they have never been observed in dipolar quantum gases. We here report on the creation of vortices in a strongly magnetic Bose-Einstein-Condensate (BEC) of ^{162}Dy atoms. We are imparting angular momentum to the BEC by the means of magnetostirring, a novel technique making use of the alignment of the dipolar atoms along the rotating magnetic field. We show that for a critical rotation frequency, the dipolar BEC starts to nucleate vortices and that the vortices arrange in stripes along the direction of the magnetic field during the rotations. The next key step will be extending the concept of magnetostirring to the recently observed supersolid states and study the vortex formation in this very exotic state of quantum matter.

Q 13.4 Mon 18:00 F303

Optimizing optical potentials with physics-inspired learning algorithms — •Martino Calzavara[1,4], Yevhenii Kuriatnikov[2], Andreas Deutschmann-Olek[3], Felix Motzoi[1], Sebastian Erne[2], Andreas Kugi[3], Tommaso Calarco[1,4], Jörg Schmiedmayer[2], and Maximilian Prüfer[2] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [3]Automation and Control Institute, TU Wien, Gußhausstraße 27-29, 1040 Vienna, Austria — [4]Institute for Theoretical Physics, Universität zu Köln, 50937 Cologne, Germany

We present our new experimental and theoretical framework which combines a broadband superluminescent diode (SLED/SLD) with fast learning algorithms to provide speed and accuracy improvements for the optimization of 1D optical dipole potentials, here generated with a Digital Micromirror Device (DMD). We employ Machine Learning (ML) tools to train a physics-inspired model acting as a digital twin of the optical system predicting the behavior of the optical apparatus including all its imperfections. Implementing an algorithm based on Iterative Learning Control (ILC), we optimize optical potentials an order of magnitude faster than heuristic optimization methods. We compare iterative model-based "offline" optimization and experimental feedback-based "online" optimization. Our methods provide a new route to fast optimization of optical potentials which is relevant for the dynamical manipulation of ultracold gases.

Q 13.5 Mon 18:15 F303

A strontium quantum gas microscope with cavity-enhanced optical lattices — •Valentin Klüsener[1,2], Dimitry Yankelev[1,2], Jan Trautmann[1,2], Sebastian Pucher[1,2], Felix Spriestersbach[1,2], Immanuel Bloch[1,3,2], and Sebastian Blatt[1,3,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Alkaline-earth atoms in optical lattices have emerged as a powerful platform for precision measurements, quantum simulation and quantum computation with neutral atoms. We present a setup combining techniques developed for optical atomic clocks and quantum gas microscopes, thus marrying high frequency resolution with microscopic spatial resolution. We demonstrate single-site and single-atom resolved fluorescence imaging of individual strontium atoms in a large and homogeneous cavity enhanced optical lattice. To prepare a two-dimensional system we optically address a single layer of the optical lattice on the ultra-narrow 1S0-3P2 transition. The required high spatial resolution is achieved by application of a magnetic field gradient and precise engineering of lattice light shifts. We perform high resolution fluorescence imaging of single atoms by employing a two color imaging scheme. Narrow-line sideband cooling suppresses heating and allows to maintain low temperatures during the imaging process.

Q 13.6 Mon 18:30 F303

Quantum Simulation of Spin 1 Heisenberg Models with Dysprosium — •Katharina Brechtelsbauer and Hans-Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

In this work, we propose Dysprosium atoms for the simulation of the one-dimensional spin-1 Heisenberg model, which is known to have a rich phase diagram including the famous Haldane phase [1]. For realizing the model, we make use of the strong dipolar exchange interactions that naturally occur in the ground state of Dysprosium due to its large total angular momentum of J=8. To implement spin-1 particles, we encode the spin degree of freedom into three Zeeman sub-levels which are

energetically isolated by applying a magnetic field. Using the density-matrix renormalization group, we analyze the ground-state properties of the resulting effective model. We find that a chain of fermionic Dysprosium atoms in a suitable magnetic field can form a Haldane state with the characteristic spin-1/2 edge modes. Furthermore, we discuss the use of AC Stark shifts and Raman-type schemes to isolate effective spin-1 systems and to increase the tunability of the model parameters.

[1] W. Chen, K. Hida, and B. C. Sanctuary, Phys Rev B 67, 104401 (2003)

Q 13.7 Mon 18:45 F303

Simulation of sympathetic cooling in a linear paul trap driven by alternative waveforms — •Paul Oskar Sund[1], Martin Kernbach[1,2], and Andreas W. Schell[1,2] — [1]Leibniz Universität, Hannover, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Linear quadrupole ion traps have been established as a versatile platform for quantum computing and atomic clocks, since they allow for an environment-isolated manipulation of multiple ions simultaneously combined with flexible optical access. However, the preparation of ion species by sympathetic cooling at room-temperature demands up to several minutes, while encountering rf-heating and scattering losses. In general, the particles dynamic is determined by the ponderomotive trap force resulting from the periodical oscillating electrical field, which is dependent on the applied waveform.

Therefore the ongoing cooling dynamics were investigated by numerically solving the Mathieu's differential equations of motion in a two-particle sympathetic cooling model under various driving waveforms and initial conditions. The simulation reveals differences in rf-heating, cooling speed and steady state energies at Coulomb-crystallization. Furthermore, shifted stability regions compared to the harmonic trap driving are found. Based on these results a further systematic investigation with alternative driving waveforms appears to be promising for improving the trapping stability and preparation times.

Q 14: Quantum Technologies: Color Centers I (joint session Q/A/QI)

Time: Monday 17:00–19:00 Location: F342

Q 14.1 Mon 17:00 F342

NMR-fingerprinting of biomolecules on the picoliter level — •Nico Striegler, Thomas Unden, Jochen Scharpf, Stephan Knecht, Christophoros Vassiliou, Jochen Scheuer, Michael Keim, John Blanchard, Martin Gierse, Mohammad Usman Qureshi, Ilai Schwartz, and Philipp Neumann — NVision Imaging Technologies GmbH

A standard method for diagnostics and analytics is nuclear magnetic resonance (NMR). Conventional NMR only function well for large enough samples and is inherently limited by the low thermal spin polarisation. The combination of nuclear spin hyperpolarisation with a microscale quantum sensor enables study of metabolism on the single-cell level. This can be used for evaluating the treatment effectiveness from tumor biopsies using only a few cells. In this study the combination of a Nitrogen-Vacancy-based quantum sensor and a hyperpolarized Fumarate solution enables heteronuclear magnetic resonance spectroscopy of liqudis in picoliter volumes. The NMR probe is based on an ensemble of negatively charged Nitrogen-Vacancy (NV) centers in a ten micrometer thick diamond layer. Hyperpolarization of the solution is based on parahydrogen induced polarization (PHIP) methods, which is done in house and then transferred to the detection volume of the quantum sensor. Microwave pulse sequences brings the NV electron spins into adjustable frequencies for detection of AC magnetic fields generated by the nuclear spins of interest.

Q 14.2 Mon 17:15 F342

Impact of Charge Conversion on NV-Center Relaxometry — •Isabel Barbosa, Jonas Gutsche, and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern, Erwin-Schroedinger-Str. 46, 67663 Kaiserslautern, Germany

Relaxometry schemes employing nitrogen-vacancy (NV) centers in diamonds are essential in biology and physics to detect a reduction of the color centers' characteristic spin relaxation (T_1) time caused by, e.g., paramagnetic molecules in proximity. However, while only the negatively-charged NV center is to be probed in these pulsed-laser measurements, an inevitable consequence of the laser excitation is the conversion to the neutrally-charged NV state, interfering with the result for the negatively-charged NV centers' T_1 time or even dominating the response signal. In this work, we perform relaxometry measurements on an NV ensemble in nanodiamond combining a 520 nm excitation laser and microwave excitation while simultaneously recording the fluorescence signals of both charge states via independent beam paths. Correlating the fluorescence intensity ratios to the fluorescence spectra at each laser power, we monitor the ratios of both charge states during the T_1 measurement and systematically disclose the excitation-power-dependent charge conversion. Even at laser intensities below saturation, we observe charge conversion, while at higher intensities, charge conversion outweighs spin relaxation. These results underline the necessity of fluorescence normalization during the measurement to accurately determine the T_1 time and characterize paramagnetic species close to the sensing diamond.

Q 14.3 Mon 17:30 F342

SiV center in nanodiamonds as a potential source for a hybrid quantum network node — •Marco Klotz[1], Richard Waltrich[1], Niklas Lettner[1], Lukas Antoniuk[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Universität Ulm — [2]Universite Francois Rabelais de Tours

Combining conventional photonic systems with the good optical and spin properties of group IV defects in diamond puts a platform for quantum technologies into reach. Here, we present measurements of characteristic properties of SiV centers in nanodiamond in comparison with bulk diamond. This reveals key benefits of a nanostructured defect host for future integration into photonic-enhancing structures, e.g. cavities.

Q 14.4 Mon 17:45 F342

Vector Magnetometry Based on Polarimetric Optically Detected Magnetic Resonance — Philipp Reuschel[1], Mario Agio[1,2], and •Assegid M. Flatae[1] — [1]Laboratory of Nano-Optics, University of Siegen, Siegen (Germany) — [2]National Institute of Optics (INO), National Research Council (CNR), Sesto Fiorentino (Italy)

Vector magnetometry has various applications in navigation systems, spintronics and life sciences. So far, different sensitive magnetic field sensors exist, for example, superconducting quantum interference devices and alkali vapor cells magnetometers. However, they suffer from high technical complexity and low spatial resolution. Recently, negatively charged nitrogen-vacancy (NV-) color centers in diamond have been developed as sensitive magnetic field sensors based on the optically detected magnetic resonance (ODMR). However, these approaches require knowledge of the crystal axes and need an external magnetic bias field or they rely on the use of single NV- centers. Recently, by combining ODMRs of ensembles of NV- color centers with polarimetry, we have been able to determine the magnitude and direction of an unknown magnetic field [1]. A longitudinal laser polarization component enables the unequivocal distinction of the four crystal axes containing NV- centers, allowing high sensitivity and robust vector magnetometry without a bias field. Our approach is general for other spin-1 color centers with C3v symmetry, and it is compatible with standard microscopy methods. Reference [1] P. Reuschel, M. Agio, A. M. Flatae, Adv. Quantum Technol. 2200077 (2022).

Q 14.5 Mon 18:00 F342

Coherent optical spectroscopy on ensembles of Silicon-vacancy color centers in diamond — •Anna Fuchs and Christoph Becher — Universität des Saarlandes, Saarbrücken 66123, Germany

Spectral hole burning (SHB) and coherent population trapping (CPT) are important techniques both in spectroscopy to characterize an ensemble of emitters in terms of their coherence times and in coherent control experiments to realize e.g. quantum memories or sensors. Single negatively charged silicon-vacancy (SiV^-) color centers in diamond are of the leading candidates for qubit systems in quantum communication [1] based on their long spin coherence and narrow optical emission lines. In addition, ensembles of SiV centers show strong coherent light-matter interaction [2], enabling applications as Raman-based optical quantum memories or for realizing single photon nonlinearities. However, the spin coherence of SiV ensembles so far remains unexplored. In this talk, we report our results of SHB and CPT measurements on two different SiV⁻- ensembles in an external magnetic field. The SHB measurements reveal in both samples an additional narrow resonance of a few MHz linewidth, which we attribute to coherent population oscillations (CPO) due to the beat frequency between the two independent input laser fields. The CPT measurements allow us to determine the Zeeman splittings not resolvable in excitation or emission spectroscopy due to inhomogeneous line broadening.

[1] Stas et al., Science 378, 557 (2022)
[2] Weinzetl et al., Phys. Rev. Lett. 122, 063601 (2019)

Q 14.6 Mon 18:15 F342

Probing the Orbital Coherence of a Tin-Vacancy Center in a Diamond Nanopillar via Coherent Population Trapping — •Cem Güney Torun[1], Joseph H. D. Munns[1], Franziska M. Herrmann[1], Gregor Pieplow[1], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Tin-vacancy color center in diamond (SnV) has gained much attention in recent years as a promising spin-photon interface. This is mainly due to its excellent optical properties resulting from the inhibited first-order coupling to external electric fields via DC Stark Shifts [1] and millisecond spin coherence through decreased phononic coupling by the large ground state splitting of 850 GHz [2]. Here, we analyze the coherence properties of the ground state orbital levels under zero magnetic field. This is implemented via a coherent population trapping experiment where two optical transitions in a lambda scheme are simultaneously driven and a reduction in the fluorescence signal is observed. Working in the spectral domain enables the extraction of a rapid 5 ps phononic decay time after analyzing the data; showing that the orbital degree of freedom is not particularly suitable for most quantum information processing applications. Finally, implications of orbital coherence times on the spin levels are considered. These experiments lay the basis for the coherent control of SnV spin states.

[1] J. Görlitz, et al. *npj Quan. Inf.* 8.1 (2022): 1-9.
[2] R. Debroux, et al. *Phy. Rev. X* 11.4 (2021): 041041.

Q 14.7 Mon 18:30 F342

Optical Microcavity with Coupled Single SiV- Centers in a Nanodiamond for a Quantum Repeater Platform — •Robert Berghaus[1], Gregor Bayer[1], Selene Sachero[1], Andrea B Filipovski[1], Lukas Antoniuk[1], Niklas Lettner[1], Richard Waltrich[1], Marco Klotz[1], Patrick Maier[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Tours University, France

A quantum repeater node requires a long-lived memory that can be addressed coherently. Additionally, efficient writing and reading of quantum states with high rates are crucial. Optical cavities can be used as spin-photon platforms to accomplish such requirements. By coupling silicon vacancy defect centers (SiV-) in a nanodiamond to an open Fabry-Pérot cavity, our work paves the way for a light-matter interface with efficient coherent control. Our fully tunable cavity formed by two Bragg mirrors allows short cavity lengths down to $\approx 1\mu$m and provides efficient coupling of the quantum emitter at liquid helium temperatures.
Here, we perform photoluminescence measurements of SiV- centers and power-dependent photoluminescence excitation of single SiV centers by collecting the cavity modulated sideband. We observe spectrally stable emitters and measure a linewidth close to the Fourier limit below $\Delta\nu = 200$ MHz. With the Purcell-enhanced cavity signal we demonstrate coherent optical driving and access the electron spin all-optical in a strong external magnetic field. The electron spin can be initialized within 67 ns and a lifetime of 350 ns is reached.

Q 14.8 Mon 18:45 F342

Entanglement in a disordered chain of coupled qubits — •Alexander Michael Minke[1], Edoardo Carnio[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany

Nitrogen-Vacancy (NV) centers in diamond are promising candidates for quantum computation due to their long coherence times. However, the robust implementation of scalable quantum registers composed of suitably coupled NV centers remains a challenge, due to limited control of their assembly. We therefore investigate the entanglement properties of arrays of dipole-coupled NV centers, the robustness of these properties against positional disorder and the dependence of the registers' resilience on their size. We find that, for chains with an even number of components, some manifolds of eigenstates show resilient entanglement properties when scaling up the system.

Q 15: Quantum Communication (joint session Q/QI)

Time: Monday 17:00–19:00 Location: F442

Q 15.1 Mon 17:00 F442

Eavesdropper location inside quantum channel using nonlinear optics — •Alexandra Popp[1,2], Birgit Stiller[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light (MPL), Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nürnberg (FAU), Erlangen, Germany.

Secure communictation is highly important in today's information age. Quantum key distribution uses the laws of quantum mechanics to offer secure key exchange between two parties. A key feature of this is the notice of eavesdropping through changes to the quantum bit error rate or excess noise of the quantum channel. Once the eavesdropper is detected, it however needs to be localized and removed from the communication channel. In a quantum channel, this can be especially challenging. We present a novel idea for localizing eavesdroppers on the cm level within quantum as well as classical communication channels using localized acoustic waves created by a correlation-based technique. Amongst other interception techniques, we show that our setup is capable of detecting interception by evanescent outcoupling with as low as 1% outcoupling.

Q 15.2 Mon 17:15 F442

Hacking QKD Sender Electronics Using Deep Learning — •Adomas Baliuka[1,2], Markus Stöcker[1,2], Michael Auer[1,2,3], Peter Freiwang[1,2], Harald Weinfurter[1,2,4], and Lukas Knips[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München — [2]Munich Center for Quantum Science and Technology, 80799 München — [3]Universität der Bundeswehr, 85577 Neubiberg — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching

Quantum key distribution (QKD) promises provably secure communication. However, the proofs make assumptions which have to be met carefully in practical implementations. Violations of the assumptions open up *side channels*, which enable an eavesdropper to obtain secret information. For a QKD sender, imperfections in quantum state preparation can lead to *quantum side channels* by encoding secret information in degrees of freedom (e.g., frequency, spatial mode) not protected by the QKD protocol. On the other hand, information can also leak via *classical side channels*, such as acoustic vibrations or classical electromagnetic emissions.

We analyze electromagnetic emissions from the electronics of our home-built BB84 QKD sender at a distance of a few centimeters. We are able to extract virtually all information about the secret key using a neural network and even observe traces of electromagnetic radiation at distances of up to a few meters. We discuss countermeasures and evaluate a revised electronics design, showing a significant reduction of emissions and attack performance.

Q 15.3 Mon 17:30 F442

Atomic arrays based on optical tweezers at the center of an optical cavity — •Lukas Hartung, Matthias Seubert, Stephan Welte, Emanuele Distante, and Gerhard Rempe — Max-Planck Institut für Quantenoptik, Hans-Kopfermann-Str.1, 85748 Garching

Future quantum networks require multi-qubit network nodes that are capable to manipulate and process quantum information locally and distribute entanglement over the entire network. Therefore, a variety of fundamental qubit-operations and quantum gates are necessary and were already demonstrated, e.g. single qubit-rotations, local [1] and remote qubit-gates [2] and efficient atom-photon entanglement [3]. However, scaling up to many qubits at one node remains an outstanding challenge.

In this talk, we present the generation of arrays of rubidium 87 atoms in an optical cavity. The atoms are loaded and trapped in an optical lattice probabilistically and are then rearranged within the lattice with the help of optical tweezers. In this way, we increase the rate of generation of atomic arrays by orders of magnitudes and, in principle, preserve the capabilities already demonstrated in the past.

[1] Welte, Stephan, et al., Photon-Mediated Quantum Gate between Two Neutral Atoms in an Optical Cavity, Phys. Rev. X 8, 011018 (2018)

[2] Daiss, Severin, et al., A quantum-logic gate between distant quantum-network modules, Science 371, 614 (2021)

[3] Thomas, Philip, et al., Efficient generation of entangled multi-photon graph states from a single atom, Nature 608, 677-681 (2022)

Q 15.4 Mon 17:45 F442

Quantum communication protocols over a 14 km urban fiber link — •Stephan Kucera, Elena Arenskötter, Christian Haen, Jonas Meiers, Tobias Bauer, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The application of existing telecom-fiber infrastructure for quantum communication protocols enables efficient development of quantum networks [1]. It also entails multiple challenges, since existing infrastructure in an urban region is often underground, or paired with the electrical overhead power line.

We report on the implementation of entanglement distribution and quantum-state teleportation over a 14 km polarization-stabilized urban dark-fiber link, which is partially underground, partially overhead, and patched in several stations. Using a type-II cavity-enhanced SPDC photon-pair source, a $^{40}Ca^{+}$ single-ion quantum memory whose transition matches the source, and quantum frequency conversion to the telecom C-band of one photon of a pair [2], we demonstrate photon-photon entanglement, ion-photon entanglement, and teleportation of a qubit state from the ion onto the remote telecom photon, all realized over the urban fiber link.

[1] H. Kimble, Nature 453, 1023*1030 (2008)

[2] E. Arenskötter et al., arXiv:2211.08841 (2022)

Q 15.5 Mon 18:00 F442

Free-space continuous-variable quantum key distribution using discrete modulation — •Kevin Jaksch[1,2], Thomas Dirmeier[1,2], Yannick Weiser[1,2], Stefan Richter[1,2], Ömer Bayraktar[1,2], Bastian Hacker[1,2], Conrad Rössler[1,2], Imran Khan[1,2], Andrej Krzic[3], Teresa Kopf[3], René Berlich[3], Matthias Goy[3], Daniel Rieländer[3], Fabian Steinlechner[3], Florian Kanitschar[4,5], Stefan Petscharning[4], Thomas Grafenauer[4], Ömer Bernhard[4], Christoph Pacher[4], Twesh Upadhyaya[5], Jie Lin[5], Norbert Lütkenhaus[5], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, Germany — [4]AIT Austrian Institute of Technology, Center for Digital Safety&Security, Vienna, Austria — [5]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Canada

In future metropolitan quantum key distribution (QKD) networks, point-to-point free-space links will allow to secure the communication beyond the existing but inflexible fiber backbone. For this purpose, we investigate a continuous-variable QKD system using a discrete modulation pattern in the polarization degree of freedom. We present our results obtained in an experiment over an urban 300m free-space link between the Federal Ministry of Education and Research (BMBF) and the Federal Office for Information Security (BSI) in Bonn.

Q 15.6 Mon 18:15 F442

Atom-Photon Entanglement over 101 km Telecom Fiber — •Yiru Zhou[1,2], Pooja Malik[1,2], Florian Fertig[1,2], Matthias Bock[3], Tim van Leent[1,2], Wei Zhang[1,2], Christoph Becher[3], and Harald Weinfurter[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Fachrichtung Physik, Universität des Saarlandes, Saarbrücken, Germany — [4]Max-Planck-Institut für Quantenoptik, Garching, Germany

The crucial task for future quantum networks is to share entanglement over large distances. For that, quantum systems are required which provide an efficient light-matter interface, long coherence times and the possibility to connect to low-loss quantum channels.

Here we present the distribution of entanglement between an atom and a photon. Spontaneous emission of a photon at 780 nm from a single, trapped Rb-87 atom is employed to obtain entanglement between the polarization of the photon and the respective Zeeman state of the atom. Raman state transfer is used to change the encoding of the atomic qubit in a combination of F=1 & F=2 hyperfine states [1]. The reduced sensitivity to magnetic fields enables one to increase the coherence time to 7 ms. Together with efficient polarization-preserving quantum frequency conversion to telecom wavelengths minimizing the photon loss [2], we demonstrate the distribution of atom-photon entanglement over 101 km telecom fiber with a fidelity ≥70.8%.

[1] M. Körber et al., Nat. Photonics 12, 18 (2018)

[2] T. van Leent et al., Nature 607, 69-73 (2022)

Q 15.7 Mon 18:30 F442

A 3km free-space link in the munich quantum network — •Michael Auer[1,2,3], Adomas Baliuka[1,2], Fabian Farina[3], Peter Freiwang[1,2], Swantje Kastrup[3], Hedwig Körfgen[3], Hanns Zimmermann[3], Nils gentschen Felde[3], Lukas Knips[1,2,4], Udo Helmbrecht[3], and Harald Weinfurter[1,2,4] — [1]Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Universität der Bundeswehr München, Neubiberg, Germany — [4]Max-Planck-Institut für Quantenoptik, Garching, Germany

Quantum key distribution (QKD) enables secure key exchange, based on fundamental laws of quantum mechanics. Widespread commercial use of this technology requires robust and scalable QKD modules paired with underlying infrastructure and proper key management.

The MuQuaNet aims to build, test and operate a secure quantum communication network with multiple nodes by employing a heterogeneous framework using various manufacturers and provide this network as a transparent service to other institutes, authorities and offices.

Here, we focus on a 3km optical free-space link using a small-size, low-power, FPGA-controlled decoy-state BB84 QKD sender operating at 850nm and 100MHz. With a modulated 1550nm beacon laser, active beam stabilization using two fast steering mirrors, synchronization as well as classical communication is achieved. This will show how to integrate individual QKD links into a network or key management solution and will yield insights to long-term effects and maintainability of QKD devices outside a well controlled environment.

Q 15.8 Mon 18:45 F442

Development and characterization of a high-rate receiver for satellite-based QKD — •Conrad Rössler[1,2], Kevin Günthner[1,2], Bastian Hacker[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudstr. 7/A3, 91058 Erlangen, Germany

Since the famous BB84 protocol was proposed in 1984, QKD has evolved to a very mature and promising quantum technology. While classical communication is being threatened by the approach of quantum computers, QKD offers an information theoretical secure way to share a key between two parties. Our high-rate receiver is designed and tested for phase-encoded satellite-based QKD. We present the corresponding discrete variable QKD protocol as well as the concept and characterization of our photon-detection-based phase locking and time synchronization of sender and receiver.

Q 16: Photonic Quantum Technologies (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: A320

Q 16.1 Tue 11:00 A320

Fluorescence Excitation of Quantum Dots by Entangled Two-Photon Absorption — •Tobias B. Gäbler[1,2], Patrick Hendra[1,2], Nitish Jain[1], Erik Prenzel[1], and Markus Gräfe[1,2,3] — [1]Fraunhofer Institute of Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, D-07745 Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Abbe Center of Photonics, Max-Wien-Platz 1, D-07745 Jena, Germany — [3]Technische Universität Darmstadt, Institute of Applied Physics, Hochschulstraße 6, D-64289 Darmstadt, Germany

Fluorescence excited by absorption of entangled light becomes a prominent candidate to tackle the challenges in the state-of-the-art two-photon imaging techniques, such as the requirement of bright excitation light and fast photobleaching. However, due to the low brightness of entangled photon pair sources used in most studies, fluorescence measurements were not feasible.

Our work addresses this issue by optimization of several experimental parts. Initially, a setup of an efficient entangled photon pair source based on nonlinear waveguides was assembled. Secondly, quantum dots were used to maximize the absorption cross sections and thus the probability to detect fluorescence photons. Additionally, we performed coherence measurements to observe influences of single-photon effects.

Our measurements of fluorescence demonstrate that obstacles like disruptive single-photon effects or insufficient photon pair rates can be handled. These results represent the next step towards an experimental realization of entangled light fluorescence microscopy.

Q 16.2 Tue 11:15 A320

Nonclassical states of light via high harmonic generation in semiconductors — •René Sondenheimer[1], Ivan Gonoskov[2], Christian Hünecke[2], Daniil Kartashov[3], Ulf Peschel[4], and Stefanie Gräfe[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Strasse 7, 07745 Jena, Germany — [2]Institute of Physical Chemistry, Friedrich Schiller University Jena, Helmholtzweg 4, 07743 Jena, Germany — [3]Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [4]Institute of Solid State Theory and Optics, Friedrich Schiller University Jena, Max-Wien-Platz 1, 07743 Jena, Germany

I will discuss the generation of higher-order harmonics from a quantum optics perspective via the interaction of a semiconductor with a coherent pump field focusing on the regime where strong-field intraband excitations dominate. While the fundamental mode undergoes intricate but sufficiently mild modifications due to nonlinear interactions, the harmonic modes can be described by coherent displacements depending on the position quadrature component of the driving laser field within our approximations. Similar to high-harmonic generation in atoms, all radiation field modes are entangled, allowing for potential novel protocols for quantum information processing with high photon numbers over a large range of frequencies.

Q 16.3 Tue 11:30 A320

Interfacing a quantum memory based on warm atomic vapour with single photons from a semiconductor quantum dot — •Benjamin Maass[1,2,3], Avijit Barua[3], Norman Vincenz Ewald[2], Leon Messner[1,2,3], Jin-Dong Song[4], Stephan Reitzenstein[3], and Janik Wolters[2,3] — [1]Optische Systeme, Humboldt Universität zu Berlin, Germany — [2]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin, Germany — [3]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [4]Center for Opto-Electronic Materials and Devices, Korea Institute of Science and Technology, Korea

The complexity of modern quantum applications demands for heterogeneous technological solutions. In particular, the excellent controllability and robustness of atomic quantum memories and the effectiveness of single photon generation with solid state emitters can serve as a cornerstone for future applications in quantum optics, e.g. synchronization and buffering of optical networks.

We present prospects of using a warm caesium vapour as storage medium for single photons at the caesium D1 line (894nm). Our quantum memory is based on electromagnetically induced transparency (EIT) in a ladder-type configuration and allows for on-demand storage and retrieval of few-photon light pulses with 20 MHz repetition rate. We achieve 1/e storage times of 20 ns and an end-to-end efficiency of 1%. The high storage bandwidth of the memory and the low read-out noise promise compatibility with single photons from deterministically fabricated quantum light sources based on InGaAs quantum dots.

Q 16.4 Tue 11:45 A320

Room-temperature quantum memory: Interfacing atomic vapours and semiconductor quantum dots — •Esteban Gómez-López[1], Quirin Buchinger[2], Tobias Huber[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, 12489 Berlin — [2]University of Würzburg, 97074 Würzburg

Quantum repeaters are a key element for scalable quantum networks, where quantum memories can substantially increase the efficiency of long-distance communications [1]. Quantum memories based on warm atomic ensembles constitute an attractive platform as they can store high-bandwidth photons [2] up to the second range [3]. Here we show an Electromagnetically Induced Transparency (EIT) quantum memory hosted in warm cesium vapour. Storage of faint coherent light pulses shows high readout efficiency. A measured bandwidth in the order of 200 MHz makes the memory compatible with the Fourier-limited emission of semiconductor Quantum Dots (QD) embedded in micropillar cavities [4]. We also present the first attempts to interface the emission from a QD-micropillar with our quantum memory by fine-tuning the emission wavelength of the emitters to the hyperfine transitions of the Cs D1 line, where the EIT memory takes place. This work sets the base for a hybrid quantum memory for single photons from a semiconductor single-photon source based on warm atomic ensembles. [1] P. van Loock et al., Adv. Quantum Technol. 3, 1900141 (2020). [2] N. Sangouard et al., Rev. Mod. Phys. 83, 33 (2011). [3] O. Katz and O. Firstenberg, Nat. Commun. 9, 2074 (2018). [4] H. Wang et al., Phys. Rev. Lett. 116, 213601 (2016).

Q 16.5 Tue 12:00 A320

Raman control for ultrahigh fidelity spin gates for the generation of large entangled photonic states with group-IV vacancies — •Gregor Pieplow[1], Joseph H. D. Munns[2], Mariano I. Monsalve[1], and Tim Schröder[1,3] — [1]Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Psi Quantum, 94304 California Palo Alto, USA — [3]Ferdinand-Braun-Institut, 12489 Berlin, Germany

Large photonic entangled states such as multiphoton Greenberger-Horne-Zeilinger (GHZ) states or cluster states (CS) play a crucial role as a resource in two key photonic quantum information applications: measurement-based quantum computing, and one-way quantum repeaters. Here, we focus on theoretically investigating the deterministic generation of photonic resource states by employing a promising class of optically active spin defects in diamond: group-IV color centers. Specifically, we investigate the generation of linear cluster states and GHZ states. Because the generation of a large entangled photonic state comprised of single photons requires many iterations of the same coherent operations on a quantum emitter, they have to be of ultra high fidelity or otherwise the quality of the state degrades exponentially. This work provides a highly detailed investigation of the optical coherent control that facilitates single and two qubit gates, which are used for the deterministic generation of highly entangled states. We also introduce an original GHZ and CS quality measure, which will underline the importance of ultrafast and high fidelity control techniques for creating large time-bin entangled photonic qubit states.

Q 16.6 Tue 12:15 A320

Ideal Single Photon Sources at Telecom Wavelengths — •Jonas Grammel[1], Julian Maisch[2], Simone Luca Portalupi[2], Peter Michler[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Univer- sität Stuttgart

Semiconductor single photon sources are fundamental building blocks for quantum information applications. The current limitations of such quantum dot sources are the emitting wavelength and insufficient collection efficiency in fiber-based implementations. In the project *Telecom Single Photon Sources* we aim to realize high brightness, fiber coupled sources of single and indistinguishable photons at the telecom wavelength for the upcoming realization of fiber-based quantum networks. We employ open cavities realized with fiber-based mirrors, in combination with InGaAs quantum dots emitting in the telecom O-band and C-band. To achieve Fourier-limited photons we utilize the lifetime reduction of the emitters via the Purcell effect. We optimize the mode matching between the cavity mode and the guided fiber mode by introducing a fiber-integrated mode-matching optics that can basically reach near-unity collection efficiency.

Q 16.7 Tue 12:30 A320

Spatially and spectraly indistinguishable single mode photons from domain-engineered crystal — •Baghdasar Baghdasaryan[1,2], Fabian Steinlechner[3,4], and Stephan Fritzsche[1,2,4] — [1]Theoretisch-Physikalisches Institut, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [4]Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany

Pure single-photon sources are currently one of the most important goals of photonic quantum technologies. A heralded single photon from spontaneous parametric down-conversion (SPDC) is a good candidate for a pure single-photon source. However, the photons from SPDC occur in pairs, that are highly correlated in space and frequency. This correlation reduces the purity of the heralded photons. Domain-engineered crystals with a Gaussian nonlinear response have been successfully used to minimize spectral correlations and enhance spectral purity in SPDC. However, a general approach, which minimizes both, spectral and spatial correlations, is still lacking. We go beyond the ansatz of the Gaussian nonlinear response and find a general nonlinear response that maximizes both the spatial and spectral purity of the SPDC emission.

Q 16.8 Tue 12:45 A320

Towards time-multiplexed pseudo-on-demand generation of single-photons in the C-band based on SPDC — •Xavier Barcons Planas[1,2,3], Leon Messner[1,2,3], Helen Chrzanowski[2], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Institute of Optical Sensor Systems, German Aerospace Center (DLR), Berlin, Germany — [3]Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Germany

The deterministic generation of single photons is crucial for photonic quantum technology applications. Spontaneous parametric down-conversion (SPDC) is one of the most prominent processes for the generation of single-photons, where a classical pump beam can spontaneously convert into (entangled) pairs of signal and idler photons. Despite significant advantages in the versatility and the possibility of room-temperature operation, photon-pairs are emitted probabilistically because of the spontaneous nature of the process. We present first results of our efforts to overcome this limitation through temporal multiplexing [1]. We herald the presence of the signal photon from a monolithic cavity SPDC source [2] by detecting the corresponding idler, and store the signal in a highly-efficient storage loop [3]. The synchronization of the source with the memory provides a pseudo-on-demand single-photon source.

[1] E. Meyer-Scott *et al.*, Rev. Sci. Instrum. **91**, 041101 (2020).
[2] R. Mottola *et al.*, Opt. Express **28**, 3159 (2020).
[3] T. Pittman *et al.*, Phys. Rev. A **66**, 042303 (2002).

Q 17: Integrated Photonics I (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: E001

Invited Talk Q 17.1 Tue 11:00 E001

Thin-film lithium niobate waveguides for integrated quantum photonic technologies — •Francesco Lenzini[1], Emma Lomonte[1], and Wolfram Pernice[1,2] — [1]University of Muenster, 48149 Muenster, Germany — [2]Heidelberg University, 69120 Heidelberg, Germany

Lithium-Niobate-On-Insulator (LNOI) has emerged in recent years as a promising platform for integrated quantum photonic technologies because of its high-index contrast, enabling the realization of waveguides with a compact footprint, large second-order optical nonlinearity, and high electro-optic coefficient. In the first part of my talk I will give a general overview about our fabrication process for the realization of low-loss LNOI waveguide circuits, with a special focus on the development of efficient fiber-to-chip interconnects based on the use of grating couplers with a metal back-reflector. In the second part of my talk, I will instead discuss some applications in integrated quantum photonic technologies of the developed LNOI circuits. Specifically, I will present the first demonstration of an electro-optically tunable LNOI waveguide network integrated on-chip with superconducting nanowire single-photon detectors (SNSPDs), as well as the realization of high-speed programmable circuits specially designed for operation with single photons emitted by a Quantum Dot source.

Q 17.2 Tue 11:30 E001

Duty cycle errors in periodically poled $LiNbO_3$ waveguides — •Sebastian Brauner, Christof Eigner, Harald Herrmann, Lara Padberg, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics,Institute for Photonic Quantum Systems (PhoQS), Warburgerstr. 100, 33098 Paderborn, Germany

Photon pair generation and quantum frequency conversion are fundamental in quantum communication. Waveguides and specifically tailored quasi-phase matching have shown an amazing potential for future quantum communication technologies, which established material platforms as $LiNbO_3$ are about to explore. However, one often observes deviations from the expected performance, i.e. a low efficiency and distorted spectral phase-matching curves. We attribute these distortions to imperfections of the period poling. To gather a profound understanding, how such imperfections impact on the device performance, we conduct theoretical and experimental studies how duty cycle errors affect the conversion characteristic.

Q 17.3 Tue 11:45 E001

Ultrabright and narrowband intra-fiber biphoton source at ultralow pump power — •Alexander Bruns[1], Chia-Yu Hsu[1,3], Sergiy Stryzhenko[1,2], Enno Giese[1], Leonid Yatsenko[2], Ite Yu[3,4], Thomas Halfmann[1], and Thorsten Peters[1] — [1]TU Darmstadt, Germany — [2]National Academy of Science of Ukraine, Kyiv, Ukraine — [3]National Tsing Hua University, Hsinchu, Taiwan — [4]Center for Quantum Technology, Hsinchu, Taiwan

Nonclassical photon sources of high brightness are key components of quantum communication technologies. We here demonstrate the generation of narrowband, nonclassical photon pairs by employing spontaneous four-wave mixing in an optically-dense ensemble of cold atoms within a hollow-core fiber.

The brightness of our source approaches the limit of achievable generated spectral brightness at which successive photon pairs start to overlap in time. For a generated spectral brightness per pump power of up to 2×10^9 pairs/(s MHz mW) we observe nonclassical correlations at pump powers below 100 nW and a narrow bandwidth of $2\pi \times 6.5$ MHz. In this regime we demonstrate that our source can be used as a heralded single-photon source. By further increasing the brightness we enter the regime where successive photon pairs start to overlap in time and the cross-correlation approaches a limit corresponding to thermal statistics.

Our approach of combining the advantages of atomic ensembles and waveguide environments is an important step toward photonic quantum networks of ensemble-based elements.

Q 17.4 Tue 12:00 E001

Realisation of an integrated source for Gaussian boson sampling — Laura Padberg, •Simone Atzeni, Michael Stefszky, Kai Hong Luo, Harald Herrmann, Benjamin Brecht, Christof Eigner, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Photonic quantum computing based on Gaussian Boson Sampling (GBS) is a quickly emerging research field, whose first implementations have demonstrated the role of single-mode squeezed states at telecom wavelength as key resources. Generally, the generation of these states relies on the process of parametric down-conversion in a nonlinear crystal, where care has to be taken to ensure that spectral correlations in the source do not lead to the generation of undesired multi-mode squeezed states. Due to its unique dispersion properties, bulk potassium titanyl phosphate (KTP) is typically employed for the generation of single-spectral-mode squeezed states at telecom wavelength. However, the performance of KTP sources will benefit from the enhanced light-matter interaction of a waveguide approach.

Here, we present the modelling, characterisation, and fabrication of a waveguide in periodically poled rubidium-doped KTP (ppRb:KTP). This system can act as a high-quality integrated source of single-mode squeezed states at telecom wavelength and can be readily employed in a GBS photonic processor.

Q 17.5 Tue 12:15 E001

Development of micro-integrated optical systems for atom-based quantum sensors — •Conrad Zimmermann, Marc Christ, and Markus Krutzik — Ferdinand-Braun-Institut (FBH), Berlin, Germany

Compact and mobile quantum sensors enable a broad range of applications in e.g. navigation and field-sensing with high sensitivity. The size and weight requirements derived from these applications place high demands on the degree of miniaturization, integration and robustness of all subsystems of such a device. Working on the physics package, we develop and qualify necessary integration technologies to realize miniaturized, ultra-stable optical systems and increase their functionality. Using these techniques, we set up a micro-integrated optical distribution system with a volume of ~25 ml to generate a crossed beam optical dipole trap. The two high-power laser beams precisely overlap in their focal points ($\omega_0 = 32\ \mu$m), and the system exhibits a high mechanical and thermal alignment stability. We present initial results from its operation in a cold atom experiment.

One approach to further reduce the overall size of a cold-atom based quantum sensor is to integrate optical setups within the vacuum system. We show development and qualification efforts for future in-UHV optical systems for atom trapping and manipulation.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1978 and 50WM1949.

Q 17.6 Tue 12:30 E001

Design and Simulation of Photonic Integrated Ion Traps — •Guochun Du[1], Elena Jordan[1], Carl-Frederik Grimpe[1], Anastasiia Sorokina[2,3], Steffen Sauer[2,3], Pascal Gehrmann[2,3], Stefanie Kroker[2,3], and Tanja E. Mehlstäubler[1,4,5] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [3]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

Ion traps are a promising platform for realizing high-performance quantum computers and atomic clocks. To make these systems scalable, integrated photonic components for guiding and manipulating laser light on a chip scale are important. We will report on finite element simulations of our integrated ion traps. In the simulations, we examined the distortion of the potential at the position of the ion due to the openings in the electrodes for the outcouplers. Our simulations indicate that a transparent conductive coating can help to smoothen the potential. Further, we study how our traps can benefit from grating outcouplers designed with shallow angles.

Q 17.7 Tue 12:45 E001

Integrated photonics for the ATIQ quantum computer demonstrator — •Carl-Frederik Grimpe[1], Guochun Du[1], Anastasiia Sorokina[2,3], Pascal Gehrmann[2,3], Steffen Sauer[2,3], Elena Jordan[1], Tunahan Gök[4,5], Radhakant Singh[4,5], Maxim Lipkin[4,5], Pragya Sah[4,5], Stephan Suckow[4], Babita Negi[5], Stefanie Kroker[1,2,3], and Tanja E. Mehlstäubler[1,6,7] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [3]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [4]AMO GmbH, Advanced Microelectronic Center Aachen, Aachen, Germany — [5]Chair of Electronic Devices, RWTH Aachen University, Aachen, Germany — [6]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [7]Laboratorium für Nano- und Quantenengineering, Hannover, Germany

The BMBF project "ATIQ" aims to develop reliable trapped-ion quantum computer demonstrators with more than 40 qubits and with multiqubit gate fidelities larger than 99.5%. To make the trapped ion systems scalable, we are developing integrated photonic systems for guiding and manipulating the laser light at the chip level. In this talk, we will discuss some design considerations to make when integrating photonics in surface ion traps. Furthermore, we will discuss the characterization of the photonic elements and benchmarking of the ion trap performance.

Q 18: Quantum Optics: Cavity and Waveguide QED I

Time: Tuesday 11:00–13:00 Location: E214

Invited Talk Q 18.1 Tue 11:00 E214

Atoms coupled to nanofibers: from topological phases to correlated photon emission — •Beatriz Olmos — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

An ensemble of emitters coupled to a common environment displays collective behaviour. This includes the enhanced and inhibited emission of photons from the ensemble (so-called super and subradiance, respectively), and the emergence of induced dipole-dipole interactions among the emitters. Among these structures, so-called nanophotonic waveguides such as single mode optical nanofibers particularly stand out, since the translationally invariant nature of the nanofiber-guided modes gives rise to infinitely ranged couplings between the emitters. In this talk, I will summarize some of the latest theoretical results in my group, where we have shown how these all-to-all interactions can facilitate the study of non-trivial topology, the emergence of phase transitions, and correlated photon emission, among other phenomena.

Q 18.2 Tue 11:30 E214

Effective mode theory for open quantum systems — •Lucas Weitzel Dutra Souto, Felix Riesterer, Dominik Lentrodt, and Andreas Buchleitner — University of Freiburg, Germany

In the frequently employed theoretical approaches for open resonator QED systems, one usually considers a quantum emitter - such as an atom - in a cavity which interacts with a few discrete electromagnetic cavity modes. Losses and leakage from the cavity are modelled via a (weak) interaction with the environment. Models that employ this treatment, as is the case for the seminal Jaynes-Cummings model and its generalizations, have been tremendously successful in describing experiments. However, these models are intrinsically phenomenological and it is not known if they hold in all situations, as the underlying approximations are still unclear. For instance, in the case of strongly leaking systems, such as plasmonic cavities, this approach is not valid anymore and various theoretical assumptions need to be reassessed. We hence try to answer the following question: Is it possible to construct from first principles a few-mode description for leaky cavities in the spirit of the Jaynes-Cummings model? This will extend our theoretical understanding of more general systems or, in the case of a negative answer, lead to a no-go theorem.

Q 18.3 Tue 11:45 E214

Crafting the dynamical structure of synchronization by harnessing bosonic multi-level cavity QED — •Riccardo J. Valencia-Tortora[1], Shane P. Kelly[1], Tobias Donner[2], Giovanna Morigi[3], Rosario Fazio[4,5], and Jamir Marino[1] — [1]JGU Mainz, Mainz, Germany — [2]ETH Zürich, Zürich, Switzerland — [3]Saarland University, Saarbrücken, Germany — [4]ICTP, Trieste, Italy — [5]Università di Napoli Federico II, Napoli, Italy

Recently, the theoretical and experimental investigation of multi-level cavity systems has gathered increasing attention. Yet, the rich diversity of dynamical responses they can host is still widely unexplored, and the few individual results call for a unifying picture both for theoretical and experimental purposes. We present a framework which could serve this scope based on a dynamical reduction hypothesis, which in summary states that the dynamics of collective observables can be described by a few-body effective Hamiltonian. Using this conjecture as a guiding principle, we intuitively explain and craft the dynamical response of an exchange model for SU(N) spins mediated by cavity photons after a quench. In this regard, we unveil the susceptibility of the dynamical response of multi-level systems to quantum fluctuations and intra-levels entanglement, observing among the others the onset of a chaotic phase characterized by exponential sensitivity to the initial conditions. To conclude, we discuss possible extensions to other spin-exchange quantum simulators and a universal conjecture for the dynamical reduction of non-integrable all-to-all interacting systems.

Q 18.4 Tue 12:00 E214

Cascaded photon emission of a single three-level ladder atom into two cavities — •Gianvito Chiarella, Tobias Frank, Pau Farrera, and Gerhard Rempe — Max Planck Institute for Quantum Optics, Garching bei München, Germany

Crossed Fiber Cavities coupled to single 87Rb atoms have proven to be a potentially useful resource for quantum communication applications [1,2]. Their main feature lies in the capability to couple two distinct light modes to two atomic transitions simultaneously with high cooperativity. This property makes them a good candidate for the investigation of fundamental phenomena in quantum optics which manifest in the presence of two vacuum fields strongly interacting with the atom. We explore the scenario where the cavities couple to two electrical-dipole transitions of a three-level ladder atom. In certain parameters regimes, we predict an effect for which the atom relaxes down the ladder states into its ground state emitting two resonant photons without populating the intermediate state. In this talk, I will present the theoretical simulation of such a model and discuss its experimental implementation.

Q 18.5 Tue 12:15 E214

Light-matter interaction at the transition between cavity and waveguide QED — •Daniel Lechner, Riccardo Pennetta, Martin Blaha, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Humboldt Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin

The interaction between a light field and an ensemble of quantum emitters is usually described in the framework of cavity quantum electrodynamics (QED) or waveguide QED. The choice depends on whether the emitters interact with a single-mode light field confined in a resonator or a propagating one, for which a continuum of frequency modes is allowed. These two branches of quantum optics share the common goal of harnessing light-matter coupling. However, they often use very different experimental set-ups and theoretical descriptions. Here, we experimentally and theoretically explore the transition from cavity to waveguide QED with an ensemble of cold atoms that is coupled to a fiber-ring resonator containing a nanofiber section. By changing the length of the resonator from a few meters up to several tens of meters, we tailor the spectral density of modes of the resonator without affecting the system's cooperativity parameter. We demonstrate that for progressively longer resonators, the paradigmatic Rabi oscillations of cavity QED gradually vanish while signatures of the dynamics typical for waveguide QED appear.

Q 18.6 Tue 12:30 E214

Relativistic formulation of quantum electrodynamical density functional theory for cavities — •Valeriia Kosheleva[1], Lukas Konecny[1], Heiko Appel[1], Angel Rubio[1,2], and Michael Ruggenthaler[1] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Center for Computational Quantum Physics (CCQ), The Flatiron Institute, 162 Fifth Avenue, New York, New York 10010, USA

Recent advances in cavity QED, particularly in polaritonic chemistry, necessitate the development of theoretical methods for describing many-electron systems strongly coupled to photons. One of the most popular ab initio approaches for modeling realistic materials is density functional theory (DFT). Recently, this theory was generalized for cavity systems [1,2] and is referred as quantum electrodynamical density functional theory (QEDFT). The matter part in QEDFT is usually treated within non-relativistic formalism which is a good approximation for light element-containing systems. However, as soon as heavier atoms are involved relativistic effects become essential for understanding the physical and chemical properties of atoms and molecules. In the present work, we introduce relativistic reformulation of cavity QEDFT. As an example, we consider the application of our formalism to study the the effect of strong coupling on absorption spectra of molecules containing heavy atoms.

[1] I. V. Tokatly, Phys. Rev. Lett. 110, 233001 (2013).
[2] M. Ruggenthaler et al., Phys. Rev. A 90, 012508 (2014).

Q 18.7 Tue 12:45 E214

Quantum Theory for Self-organization in Many-body Cavity QED — •Tom Schmit[1], Simon Jäger[2], Tobias Donner[3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [3]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

Ensembles of atoms strongly coupled with the electric field of an optical cavity offer a formidable laboratory for studying the out-of-equilibrium dynamics of long-range systems in the quantum regime. In this work, we derive by means of the formalism developed in Ref. [1] a quantum master equation describing the dynamics of atoms which interact with a multimode high-finesse cavity. We then derive the BBGKY hierarchy and analyse the predictions in several relevant limits. Our theory reproduces the results of the experiment of Ref. [2] and provides a powerful tool for singling out the individual contributions to the onset of metastability in quantum globally-interacting systems.

[1] S. B. Jäger, T. Schmit, G. Morigi, M. J. Holland, and R. Betzholz, Phys. Rev. Lett. **129**, 063601 (2022).
[2] A. Morales, P. Zupancic, J. Léonard, T. Esslinger, and T. Donner, Nature Materials **17**, 686 - 690 (2018).

Q 19: Precision Spectroscopy of Atoms and Ions II (joint session A/Q)

Time: Tuesday 11:00–12:45 Location: F303

Q 19.1 Tue 11:00 F303

Highly-sensitive photodetachment spectroscopy in an MR-ToF device — •Franziska Maria Maier[1,2] and Erich Leistenschneider[1] — [1]ISOLDE/CERN — [2]Universität Greifswald

For the MIRACLS and GANDALPH collaboration.

The electron affinity (EA) reflects the energy released when an electron is attached to a neutral atom. An experimental determination of this quantity serves as an important benchmark for atomic models describing electron-correlation effects [1]. However, the EA of several radioactive elements is still unknown and detailed information about isotope shifts or hyperfine splittings of EAs are only available for a handful of cases, mainly with modest precision.

Exploiting the low-energy version of the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) [2], we have initiated a high-precision measurement of the isotope shift in the electron affinity. By trapping ion bunches between the two electrostatic mirrors of MIRACLS multi-reflection time-of-flight (MR-ToF) device, the same ion bunch is probed by the spectroscopy laser repeatedly. Thus, the signal sensitivity is 3-4 orders of magnitude higher compared to conventional single-pass photodetachment experiments, see e.g. [1].

I will introduce the novel technique, present the first experimental results on Chlorine and discuss future possibilities of an MR-ToF device for highly sensitive and high-precision measurements of EAs for various radioactive samples.

[1] D. Leimbach et al., Nat Commun 11, 3824 (2020).
[2] S. Sels et al., Nucl. Instr. Meth. Phys. Res. B 463, 310 (2020).

Q 19.2 Tue 11:15 F303

Nuclear polarization effects in atoms and ions — Victor V. Flambaum[1,2,3], Igor B. Samsonov[1], Hoang Bao Tran Tan[1,4], and •Anna V. Viatkina[2,3,5,6] — [1]School of Physics, University of New South Wales, Sydney 2052, Australia — [2]Helmholtz Institute Mainz, GSI Helmholtzzentrum für Schwerionenforschung, 55099 Mainz, Germany — [3]Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [4]Department of Physics, University of Nevada, Reno, Nevada 89557, USA — [5]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [6]Institute of Mathematical Physics, Technical University Braunschweig, 38106 Braunschweig, Germany

Precision isotope shift spectroscopy offers an opportunity to search for new physics by means of measuring King plot (KP) nonlinearities. However, KP nonlinearities might arise from standard-model effects as well, thus obscuring possible new-physics signal. One of such effects is the variation of nuclear polarizabilities between isotopes. Even though this effect is estimated to be relatively small and not the leading contribution to KP nonlinearity, it should not be overlooked in the interpretation of the data. In our work, we calculated energy-level shifts due to electric-dipole and -quadrupole nuclear polarization for 1s, 2s, $2p_{1/2}$ states in hydrogenlike ions, and for high-ns valence states in neutral atoms with $Z \geq 20$. We fit the results with elementary functions of nuclear parameters and derive a set of effective potentials which may be used to calculate polarization energy-level shifts in many-electron atoms and ions.

Q 19.3 Tue 11:30 F303

Enhancing Atom-Photon Interaction with Novel Integrated Nano-photonic Resonators — •Benyamin Shnirman — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Germany

The marriage of thermal atomic vapor with nanophotonics provides a unique testbed for the manipulation of atom-atom and atom-photon interactions. While benefitting from strong miniaturisation, integration and scalability, this platform struggles with short atom-light interaction due to the thermal motion.

In order to overcome this dephasing mechanism, we need atom-light interaction to reach the strong coupling regime. A suitable candidate is a photonic crystal cavity (PhC), which combines a tight mode confinement with a high quality factor. In order to create an interface for atom-light interaction, we have developed a novel fabrication technique to suspend PhC's. This allows us to investigate cavity QED effects that are sensitive to single photons and single atoms. We present first characterization data of the fabricated PhC's and compare it to the simulation results.

Our other lines of research on nanophotonics and thermal atoms include the use of the Rydberg blockade effect on chip to generate single photons. In order to couple to the Rydberg states efficiently, the light field is locally enhanced by ultralow-loss micro-ring resonators.We also study topological edge states in arrays of ring resonators and how thermal atoms can be used to study the effect of optical nonlinearity on the bulk and edge modes.

Q 19.4 Tue 11:45 F303

Minimizing entanglement of sources of P,T-violation with complementary low-energy experiments — •Konstantin Gaul and Robert Berger — Fachbereich Chemie, Philipps-Universität Marburg,Hans-Meerwein-Straße 4, 35032 Marburg, Germany

The detection of an atomic or molecular P,T-odd electric dipole moment (EDM) would be a direct evidence of physics beyond the Standard Model. Internal enhancement effects render atoms and molecules very promising candidates for a first direct detection of P,T-violation. The EDM of an atom or molecule stems from various fundamental sources of P,T-violation, such as P,T-odd currents or EDMs of elementary particles [1]. Therefore, interpretations and predictions of EDMs are difficult and several experiments are required for a global model-independent analysis of the results [2]. In this contribution all sources of the P,T-odd EDMs of atoms and molecules are studied within a simple qualitative electronic-structure model in terms of electronic and nuclear angular momenta and the nuclear charge number. For comparison accurate calculations of the electronic structure parameters [3] of most experimentally relevant atoms and molecules are performed and selection of good candidates for future experiments is discussed in the light of minimizing the coverage region in the global P,T-odd parameter space.

[1] Khriplovich, Lamoreaux, CP Violation without Strangeness (1997).
[2] Jung, JHEP 2013, 168 (2013); Engel *et al.*, PPNP 71, 21 (2013); Chupp, Ramsey-Musolf, PRC 91, 035502 (2015).
[3] Gaul *et al.*, PRA 99, 032509 (2019); JCP 152, 044101 (2020).

Q 19.5 Tue 12:00 F303

Path integral formalism for radiative corrections in bound-state QED — •Sreya Banerjee and Zoltán Harman — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

A step-by-step theory of radiative corrections in bound-state quantum electrodynamics is developed using Feynman's path integral formalism. As a first step, we derive the free Dirac propagator in spherical coordinates. This is followed by the derivation of the Dirac-Coulomb Green's function (DCGF) in the Furry picture by reducing it in a basis such that the effective action becomes similar to that of the non-relativistic hydrogen atom. As such, the DCGF is obtained in closed form along with the energy spectrum of the bound states. In the final step, the lowest-order vacuum polarization correction and one-loop self-energy correction to the energy levels of bound electrons are calculated using perturbative path integral formalism. Starting from an interparticle classical action, we arrive directly at the propagators of quantum electrodynamics. The energy level shifts are then calculated from the perturbative shift of poles of the Green's functions obtained.

Q 19.6 Tue 12:15 F303

Trapping and cooling Th ions with Ca ion crystal for quantum logic spectroscopy — •Azer Trimeche[1], Jonas Stricker[2,3], Can Patric Leichtweiss[1], Valerii Andriushkov[2], Dennis Renisch[2,3], Dmitry Budker[1,2], Christoph E. Düllmann[2,3,4], and Ferdinand Schmidt-Kaler[1] — [1]QUATUM, Institute of Physics, Johannes Gutenberg-Universität Mainz — [2]Helmholtz-Institut Mainz — [3]Department of Chemistry, Johannes Gutenberg-Universität Mainz — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Thorium isotopes became of high interest in the search for new physics, and fundamental physics tests, because of their unique nuclear and atomic properties. The Trapping And Cooling of Thorium Ions in Calcium crystals (*TACTICa*) project develops ion trapping and spectroscopic techniques for a precise determination of the nuclear moments, hyperfine intervals, and isotope shifts with different Th isotopes. For the production, we dispose of two different sources: an ion recoil source [1] and a laser ablation source [2]. Th ions are trapped in a Ca^+ crystal [3], tagged by fluorescence calorimetry technique [4], cooled down sympathetically by polarization gradient cooling of Ca^+ crystal [5], and investigated by quantum logic spectroscopy technique.

[1] R. Haas et al., Hyperfine interactions 241 (2020) 25.
[2] K. Groot-Berning et al., *PRA* 99 (2019) 023420.
[3] K. Groot-Berning et al., *PRL* 123 (2019) 106802.
[4] M. Gajewski et al. *PRA* 106 (2022) 033108.
[5] W. Li et al., *NJP* 24(4) (2022) 043028.

Q 19.7 Tue 12:30 F303

Metallic magnetic calorimeters: Novel detectors for high-resolution X-ray spectroscopy — •D. Hengstler[1], A. Abeln[1], S. Allgeier[1], A. Brunold[1], L. Eisenmann[1], M. Friedrich[1], A. Gumberidze[2], M.-O. Herdrich[2,3,4], F. Kröger[2,3,4], P. Kuntz[1], A. Fleischmann[1], M. Lestinsky[2], E. Menz[2,3,4], A. Orlow[1], Ph. Pfäfflein[2,3,4], U. Spillmann[2], B. Zhu[4], G. Weber[2,3,4], Th. Stöhlker[2,3,4], and C. Enss[1] — [1]KIP, Heidelberg University — [2]GSI, Darmstadt — [3]IOQ, Jena University — [4]HI Jena

Metallic magnetic calorimeters (MMCs) are energy-dispersive X-ray detectors which provide an excellent energy resolution over a large dynamic range combined with a very good linearity. They are operated at mK temperatures and convert the energy of each incident photon into a temperature rise which is monitored by a paramagnetic sensor.

To probe QED, we developed the 2-dimensional detector array maXs-100. The detector features 8x8 pixels with an active detection area of $1\,\mathrm{cm}^2$ and a stopping power of 40 % at 100 keV. An absolute energy calibration on eV-level as well as an energy resolution of 40 eV (FWHM) at 60 keV were demonstrated. We discuss the detector performance during the recent beam time at the ion storage ring CRYRING@FAIR (Darmstadt), where electron transitions within highly charged, He-like U^{90+} ions were studied and present ongoing detector improvements and possible future applications.

This work was conducted in the framework of the SPARC collaboration, exp. E138 of FAIR Phase-0 supported by GSI. We acknowledge substantial support by ErUM-FSP APPA (BMBF no 05P19VHFA1).

Q 20: Quantum Gases: Bosons II

Time: Tuesday 11:00–13:00 Location: F342

Q 20.1 Tue 11:00 F342

Bose-Einstein Condensation of Photons in a Four-Site Lattice Potential — •Niels Wolf, Andreas Redmann, Christian Kurtscheid, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Deutschland

Bose-Einstein condensation can be observed with ultracold atomic gases, polaritons, and since about a decade ago also with low-dimensional photon gases. Cold atomic gases in lattice potentials are usually prepared following the creation of a condensate by transferring it into the periodic potential, while in recent work with photon gases direct condensation into a coherently split state of light has been realized [1]. Here we report on experimental work directed at realizing thermalized photon gases in periodic potentials of increased complexibility, i.e. beyond a double well.

Our experiments use a controlled mirror surface delamination technique to imprint variable potentials for light in a dye-filled optical microcavity environment. Photons thermalize by repeated absorption re-emission processes on the dye molecules in a four-site lattice potential superimposed by a weak harmonic trapping potential. We observe Bose-Einstein condensation of photons in the four-fold split coherent superposition of the localized microsites wave function representing the system ground state in the microcavity.

[1] C. Kurtscheid et al., Science 366, 894 (2019)

Q 20.2 Tue 11:15 F342

Many-body interference at the onset of chaos — •Eric Brunner[1,2], Lukas Pausch[1,2,3], Edoardo G. Carnio[1,2], Gabriel Dufour[1,2], Alberto Rodríguez[4], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104, Freiburg, Germany — [3]CESAM Research Unit, University of Liège, 4000 Liège, Belgium — [4]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain

We unveil the signature of many-body interference across dynamical regimes of the Bose-Hubbard model. Increasing the particles' indistinguishability enhances the temporal fluctuations of few-body observables, with a dramatic amplification at the onset of quantum chaos. By resolving the exchange symmetries of partially distinguishable particles, we explain this amplification as the fingerprint of the initial state's coherences in the energy eigenbasis. In the domain of fully developed quantum chaos, ergodic delocalisation of the eigenstates suppresses this fingerprint.

Q 20.3 Tue 11:30 F342

Dynamical characterization of the chaotic phase in the Bose-Hubbard model — David Peña Murillo and •Alberto Rodríguez — Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain

We study the dynamical manifestation of the Bose-Hubbard model's chaotic phase [1] by analysing the temporal behaviour of connected two-point density correlations on experimentally accessible time scales up to a few hundred tunneling times. The time evolution of initial Mott states with unit density in systems including up to 17 bosons (Hilbert space dimension $\approx 10^9$) reveals that the chaotic phase can be unambiguously identified from the early time fluctuations of the considered observable around its equilibrium value [2]. The emergence of the chaotic phase is also seen to leave an imprint in the initial growth of the time signals. The possibility to discern specific features of this many-body chaotic phase, on top of the universal prediction of random-matrix theory, from these experimentally accessible measures is explored.

[1] L. Pausch *et al.*, Phys. Rev. Lett. 126, 150601 (2021)
[2] D. Peña Murillo, MSc Thesis, Universidad de Salamanca (2022)

Q 20.4 Tue 11:45 F342

Orbital dynamics of bosons in the second Bloch band of an optical lattice — •José Vargas[1,2], Marlon Nuske[1], Raphael Eichberger[1], Carl Hippler[1], Ludwig Mathey[1,2], and Andreas Hemmerich[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany — [2]The hamburg center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

We explore Josephson-like oscillations of a Bose-Einstein condensate populating the second Bloch band of a bipartite optical square lattice, which provides a double well structure with two inequivalent, degenerate energy minima. An oscillation of the relative population difference between the two energy minima of the second band is observed. The oscillation frequency depends on the ratio of two distinct collisions processes: the on-site collision term of atoms in either of the three local orbitals in shallow and deep wells of the lattice, and a flavour changing collision. The observations are compared to the predictions given by a full quantum model limited to only two single-particle modes neglecting dissipation, which reproduces the measured oscillations and show the correct dependency of the oscillation frequency on the ratio among the strength of the aforementioned collision terms.

Q 20.5 Tue 12:00 F342

Stability of vortices in dipolar droplets — Milan Radonjić[1,2], •Antun Balaž[2], and Axel Pelster[3] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

Vortices in dipolar Bose-Einstein condensates have been studied theoretically and numerically for a long time, but have proved to be elusive and were experimentally observed only very recently [1]. Based on variational calculations, it was suggested [2] that vortices may also exist in dipolar droplets [3], exotic quantum states that emerge due to quantum fluctuations [4]. Here we investigate if self-bound dipolar droplets can support vortices using numerical approach based on the extended Gross-Pitaevskii equation, which includes quantum depletion and finite-size corrections. We also study dynamical stability of such vortex states for experimentally relevant values of system parameters.

[1] L. Klaus et al., In press, Nat. Phys. (2022).
[2] A. Cidrim et al., Phys. Rev. A **98**, 023618 (2018).
[3] H. Kadau et al., Nature **530**, 194 (2016).
[4] A. R. P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011); Phys. Rev. A **86**, 063609 (2012).

Q 20.6 Tue 12:15 F342

Optimal route to quantum chaos in the Bose-Hubbard Hamiltonian — •Lukas Pausch[1,2], Edoardo G. Carnio[2,3], Alberto Rodríguez[4], and Andreas Buchleitner[2,3] — [1]Département de Physique, Université de Liège, Belgium — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany — [3]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Germany — [4]Departamento de Física Fundamental, Universidad de Salamanca, Spain

The dependence of the chaotic phase of the Bose-Hubbard Hamiltonian [1,2] on particle number, system size and particle density is investigated in terms of spectral and eigenstate features. Within the energy and parameter range where chaos fully unfolds, the expectation value and the eigenstate-to-eigenstate fluctuations of the fractal dimensions of Bose-Hubbard eigenstates show clear signatures of ergodicity and are well described by random-matrix theory (RMT) [1,2]. As the limit of infinite Hilbert space dimension is approached along different directions, the fastest convergence to the random-matrix predictions is achieved at fixed particle density $\lesssim 1$ [3]. Despite the agreement on the level of low-order statistical moments, the model is ever more distinguishable from RMT in terms of its full fractal dimension distributions as Hilbert space grows. These results provide evidence of a way to discriminate among different many-body Hamiltonians in the chaotic regime.

[1] L. Pausch et al., Phys. Rev. Lett. 126, 150601 (2021)
[2] L. Pausch et al., New J. Phys. 23, 123036 (2021)
[3] L. Pausch et al., J. Phys. A 55, 324002 (2022)

Q 20.7 Tue 12:30 F342

Full quantum simulations of Bose gases with the complex Langevin method — •Philipp Heinen and Thomas Gasenzer — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer

Feld 227, 69120 Heidelberg

While path integrals can be straightforwardly evaluated by standard Monte Carlo methods in the case of a real action, these are not applicable for a complex action because the interpretation of the integrand as a probability density is lost in this case, a fact that is commonly known as sign problem. This hinders ab initio simulations of the interacting Bose gas in the field-theoretic framework, since the purely imaginary Berry phase term in its action causes a sign problem even in thermal equilibrium. The complex Langevin (CL) algorithm is a generic, model-independent approach to tackle the sign problem by recasting the path integral into a stochastic Langevin equation and by complexifying the originally real degrees of freedom of the problem. While it has a long-standing history in high energy physics, its application to ultracold atoms is rather recent. In my talk I want to demonstrate that CL is able to simulate interacting bosons from first principles and show applications to the BKT transition and the physics of dipolar Bose gases.

Q 20.8 Tue 12:45 F342

An Atomic Mode Parametric Amplifier Mediated by Cavity Photons — •Fabian Finger, Rodrigo Rosa-Medina, Nicola Reiter, Panagiotis Christodoulou, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Parametric amplification is a fundamental concept of nonlinear dynamics, occurring in fields so diverse as mechanics, electronics, and atomic physics. In the past, ultracold quantum gases exhibiting short-range contact interactions have been used to demonstrate parametric amplification of atomic modes. Here, we make use of global-range interactions in an optical cavity to realize a fast parametric amplifier producing atomic pairs in specific spin and momentum modes. Our implementation relies on Raman scattering between spin levels in a spinor Bose-Einstein condensate, induced by the interplay of a running-wave transverse laser and the vacuum field of the cavity. Detuned from Raman resonance, a four-photon process gives rise to effective spin-mixing dynamics. We observe pair production of signal and idler atoms in tens of microseconds and demonstrate its nonlinear character by varying the number of atoms in the pump reservoir. We extend our results to a regime exhibiting two concurring pair production channels and observe correlated momenta between the highly fluctuating signal and idler modes, verifying the phase matching condition of the parametric amplifier. Our results demonstrate a new experimental platform for fast atomic parametric amplification and provide prospects for matter-wave interferometry using entangled motional states.

Q 21: Quantum Technologies: Color Centers II (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: F442

Q 21.1 Tue 11:00 F442

Purcell-Enhanced Emission from Individual SiV^- Center coupled to a Photonic Crystal Cavity — •Niklas Lettner[1,2], Lukas Antoniuk[1], Konstantin Fehler[1,2], Anna P. Ovvyan[3], Nico Gruhler[3], Viatcheslav N. Agafonov[4], Wolfram H.P. Pernice[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Universite F. Rabelais, 37200 Tours, France

The combination of classical integrated photonic structures with color centers in diamond, like the Silicon Vacancy (SiV^-) Center, offer a promising platform for on-chip quantum optics experiments. We functionalize classical silicon nitride photonic crystal cavities with SiV^- color centers in nanodiamonds in a hybrid approach. We show the experimental results coupling SiV^- centers efficiently to a photonic crystal cavity mode and the Purcell enhanced emission of individual SiV^- transitions [1]. By utilizing two mode coupling we achieved lifetimes of 460 ps [2].

[1] Fehler, Konstantin G., et al. Nanophotonics 9.11 (2020): 3655-3662.

[2] Fehler, Konstantin G., et al. ACS Photonics 8.9 (2021): 2635-2641.

Q 21.2 Tue 11:15 F442

Fabrication and characterization of μm-thin color center enriched diamonds for an open microcavity quantum network node — •Colin Sauerzapf[1,2], Julia Brevoord[1], Julius Fischer[1], Yanik Herrmann[1], Leonardo Wienhoven[1], Matteo Pasini[1], Laurens Feije[1], Matthew Weaver[1], Maximilian Ruf[1], Jörg Wrachtrup[2], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands — [2]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany

Quantum network nodes are an essential building block to realize a Quantum Internet [1]. Color centers in diamond, like the established Nitrogen-Vacancy (NV) with its long spin coherence and spin register capabilities or the emerging Tin-Vacancy (SnV) centers, are promising candidates to realize such quantum nodes [2]. Integrating the color center into an open microcavity and therefore boosting the emission of coherent photons via the Purcell effect can significantly improve the entanglement rate of the system [3, 4]. Here we present a fabrication method for the required μm-thin color center enriched diamond platelets bonded to a Bragg mirror as well as the characterization of those samples in terms of emitter properties and performance in an open microcavity [5].

[1] S. Wehner et al., Science 362, 6412 (2018) [2] M. Ruf et al., J. Appl. Phys. 130, 070901 (2021) [3] M. Ruf et al., Phys. Rev. Applied 15, 024049 (2021) [4] E. Janitz et al., Optica 7, 1232-1252 (2020) [5] M. Ruf et al., Nano Lett. 19, 6, 3987*3992 (2019)

Q 21.3 Tue 11:30 F442

Overcoming spectral diffusion of NV defect centers in diamond nanostructures for enhanced entanglement generation — •Laura Orphal-Kobin[1], Kilian Unterguggenberger[1], Tommaso Pregnolato[1,2], Natalia Kemf[2], Mathias Matalla[2], Ralph-Stephan Unger[2], Ina Ostermay[2], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

In large-distance quantum networks, quantum nodes are entangled by single photons. Using NV defect centers in diamond, network entanglement protocols were demonstrated in bulk-like microstructured samples. Performances could be significantly improved by coupling NVs to nanostructures, which increases the photon collection efficiency into a particular optical mode. However, ionization of surface defects leads to spectral diffusion of the NV zero-phonon-line resonance.

We demonstrate NVs in nanostructures that exhibit spectrally stable emission suited for entanglement generation [1]. Choosing a substrate with a high density of bulk nitrogen defects incorporates natural NVs and seems to screen fluctuating electric fields from the surface. Moreover, long ionization times allow for resonant control sequences in which high energy pulses can be circumvented for many entanglement attempt repetitions (optical π-pulses). By suppressing spectral diffusion, we propose spin-photon entanglement rates on the order of hundreds of kHz using NVs in nanostructures.

[1] L. Orphal-Kobin et al., arXiv:2203.05605 (2022).

Q 21.4 Tue 11:45 F442

High-precision localization of color centers in diamond for deterministic coupling to quantum photonic nanostructures — •Maarten H. van der Hoeven[1], Julian M. Bopp[1], Maximilian Kähler[1], Tommaso Pregnolato[1,2], Marco Stucki[1,2], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Quantum photonic circuits are fundamental building blocks for quantum information applications, like secure communication or quantum computing. In the past decades, it has been demonstrated that color centers in diamond have excellent properties to serve as qubits in such systems [1]. To create an efficient spin-photon interface, the color centers have to be coupled to quantum photonic nanostructures. The scalable fabrication of such devices with high yield and optimal performance requires deterministic alignment techniques [2]. This is achieved with high-precision localization of color centers in bulk diamond with uncertainties of a few tens of nanometers. Our approach is to determine the color center positions relative to alignment markers etched into the diamond's surface and subsequently fabricate nanostructures around them [3]. This technique allows for a pre-selection of the emitters and only the ones with the most suitable properties are chosen and integrated into a photonic device.

[1] M. Ruf et al., *Journal of Applied Physics* 130, 070901 (2021)
[2] S. Rodt et al., *J. Phys.: Condens. Matter* 32, 153003 (2020)
[3] T. Pregnolato et al., *APL Photon.* 5, 086101 (2020)

Q 21.5 Tue 12:00 F442

A novel open microcavity setup for an efficient spin-photon interface with diamond color centers — •Julius Fischer[1], Yanik Herrmann[1], Julia Brevoord[1], Colin Sauerzapf[1,2], Leonardo Wienhoven[1], Matteo Pasini[1], Laurens Feije[1], Matthew Weaver[1], Maximilian Ruf[1], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands — [2]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany

Open microcavities are capable of equipping color centers in diamond with an efficient spin-photon interface [1,2] enabling their use as quantum nodes for quantum internet applications [3]. The well-established Nitrogen-Vacancy (NV) center with its long spin coherence times and spin register capabilities as well as the emerging Tin-Vacancy (SnV) center are two promising candidates. We recently showed Purcell enhancement under resonant excitation of NV centers in open microcavities [4]. However, the performance was limited by cavity length variations due to vibrations [4]. Here we present a new cryogenic low-vibration open microcavity setup including first measurements on defect center enriched μm-thin diamond samples.

[1] M. Ruf et al., Journal of Applied Physics 130, 070901 (2021) [2] E. Janitz et al., Optica 7, 1232-1252 (2020) [3] S. Wehner et al., Science 362, 6412 (2018) [4] M. Ruf et al., Phys. Rev. Applied 15, 024049 (2021)

Q 21.6 Tue 12:15 F442

Advances in Nanoscale Nuclear Magnetic Resonance with NV centers in diamond — •Marcel Martin[1], Nicolas Palazzo[2,3], Erik Knall[2], Daniel Kim[2,3], Nadine Meister[2], Ryan Gelly[2,3], Ryan Cimmino[2], Bartholomeus Machielse[2], Elana Urbach[2], Mikhail Lukin[2], Hongkun Park[2,3], and Nabeel Aslam[1] — [1]Institute of Condensed Matter Physics, Technische Universität Braunschweig, Braunschweig, Germany — [2]Department of Physics, Harvard University, Cambridge, USA — [3]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, USA

Limitations of traditional nuclear magnetic resonance (NMR) can be overcome by using Nitrogen vacancy (NV) centers in diamond as local NMR probes which rely on statistical rather than thermal polarisation.

Proof-of-concept NMR measurements with NV centers have successfully been demonstrated in the past but revealed new challenges. One of them being the fast diffusion of molecules in liquids out of the detection volume, prohibiting NMR sensing by the NV centers. This can be solved by confining liquids in close proximity to the NV sensor. We realized this by structuring the diamond surface with nanowells, which function as traps for zeptoliter scale samples. In addition we demonstrated the controlled creation of NV centers underneath these nanostructures. We present NMR data measured with NV centers in such devices.

The promising technique of nanoscale NMR using NV centers is not restricted to liquids though but can be applied to a wide variety of materials. We will discuss a selection of potential applications.

Q 21.7 Tue 12:30 F442

Highly-efficient extraction of single photons from silicon vacancy in diamond using plasmonic nanoantenna — Ilya Fradkin[1], Mario Agio[2], and •Dmitry Fedyanin[1] — [1]Dolgopudny, Moscow, Russia — [2]University of Siegen, Siegen, Germany

Color centers in diamond and related wide-bandgap semiconductors are considered as one of the most promising quantum optoelectronic systems for single-photon sources and spin qubits. However, one of the major obstacles towards their practical exploitation is the high refractive index of diamond, which limits the maximum photon extraction efficiency to only a few percent for a horizontally oriented dipolar emitter, while for a vertically oriented emitter, the collection efficiency is even lower. At the same time, for practical applications, the efficiency of photon extraction of higher than 70% is typically required even at 100% quantum efficiency of the emitter. In this work, we develop a plasmonic nanoantenna that not only dramatically enhances the quantum efficiency of the silicon-vacancy (SiV) center in diamond but also improves the collection efficiency of the vertically oriented emitter by more than two orders of magnitude. We numerically demonstrate that the proposed nanoantenna allows to achieve the collection efficiency of more than 85%. Even more remarkable result is that the collection efficiency almost does not depend on the distance from the SiV center to the nanoantenna at distances from 10 to 100 nm and exceeds 80%, which is particularly beneficial for practical applications.

Q 21.8 Tue 12:45 F442

Fabrication of suspended "Sawfish" photonic crystal cavities in diamond — •Tommaso Pregnolato[1,2], Marco Stucki[1,2], Julian Bopp[1,2], Maarten van der Hoeven[2], and Tim Schröder[1,2] — [1]Ferdinand-Braun-Institut gGmbH, Berlin, Germany — [2]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany

Color centers in diamond are a promising candidate for the development of quantum photonic applications: for example, their long spin-coherence times make them the optimal choice for building spin-based quantum networks [1]. Such networks will be formed by many nodes containing color centers that are all interconnected by photonic channels. An efficient interface between spin and photon is key for the success of such a system, as it enables the transfer of information from the stationary qubits (i.e. the spins) to the flying qubits (i.e. the propagating photons). Such interface can be achieved by coupling a defect center to a photonic crystal cavity [2]. Here, we report on our progress of fabricating such photonic crystal cavities, based on our recently proposed "sawfish" cavity design [3]. Our design is optimized for enhancing the interaction between tin-vacancy centers in diamonds and single-mode light fields. We present our fabrication procedure to obtain such suspended devices, our investigations on how different parameters affect the relevant etching rates and our first optical characterizations.

[1] M. Atatüre, et al., Nat. Rev. Mater. 3, 38-51 (2018) [2] T. Schröder, et al, J. Opt. Soc. Am. B 33, B65-B83 (2016) [3] J. Bopp, et al., arXiv:2210.04702 (2022)

Q 22: Poster II

Time: Tuesday 16:30–19:00 Location: Empore Lichthof

Q 22.1 Tue 16:30 Empore Lichthof

Conformal duality of Bose-Einstein condensates with two- and three-body interactions — •David Reinhardt[1], Matthias Meister[1], Dean Lee[2], and Wolfgang P. Schleich[3] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Michigan State University, Department of Physics and Astronomy, East Lansing, Michigan, USA — [3]Institute of Quantum Physics, Ulm University, Ulm, Germany

It is well known that the eigenstates of nonlinear quantum systems (e.g. Bose-Einstein condensates described by the Gross-Pitaevskii equation) differ from those of the linear Schrödinger equation [1]. For instance, solitons only occur in nonlinear systems. When additionally considering three-body interactions new solution types emerge [2]. By analyzing the different solution spaces, we find that there exists a conformal duality between systems with two- and three-body interactions. This allows to predict the properties in the three-body case by means of the two-body case. For example, irregular two-body solutions can become bound solutions when including three-body interactions.

[1] L. D. Carr et al., PRA 62, 063610 (2000).
[2] H. Schürmann, PRE 54, 4312 (1996).

Q 22.2 Tue 16:30 Empore Lichthof

Matter-wave lensing of shell-shaped Bose-Einstein conden-

sates — •Patrick Boegel[1], Alexander Wolf[2], Matthias Meister[2], and Maxim Efremov[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, D-89081 Ulm, Germany — [2]German Aerospace Center (DLR), Institute of Quantum Technologies, D-89081 Ulm, Germany

Motivated by the recent experimental realization [1] of ultracold quantum gases in shell topology, we propose a straightforward implementation of matter-wave lensing techniques for shell-shaped Bose-Einstein condensates. This approach allows to significantly extend the observation time of the condensate shell during its free expansion and enables the study of novel quantum many-body effects on curved geometries. With both analytical and numerical methods, we derive optimal parameters for realistic lensing schemes to conserve the shell shape of the condensate for times up to hundreds of milliseconds [2].

This project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under Grants Nos. 50WM1862 and 50WM2245B.

[1] Nature 606, pages 281-286 (2022)
[2] P Boegel, et. al, arXiv:2209.04672

Q 22.3 Tue 16:30 Empore Lichthof

Understanding the dynamics of quantum mixtures for dual species atom interferometry in space — •Priyanka Guggilam.L[1], Jonas Böhm[1], Baptist Piest[1], Ernst Rasel.M[1], and the MAIUS team[1,2,3,4,5,6] — [1]Instiut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]FBH Berlin — [4]DLR Instiut für Raumfahrtsysteme, Bremen — [5]Instiut für Physik, HU Berlin — [6]Instiut für Quantenoptik, Universität Mainz

The MAIUS (Matter wave interferometry under microgravity) project aims to demonstrate atom interferometry in space as a promising tool for precision measurements, e.g., of Einstein's equivalence principle (EEP), with accuracies that couldn't be achieved with classical tests. With the launch of MAIUS-1, it was possible to create the first BECs in space using Rb-87 atoms and performing interference experiments with these macroscopic quantum objects. In the MAIUS-2/3 missions, we concentrate on the understanding of the dynamics of K-41 and Rb-87 quantum mixtures in microgravity and to utilize them as sources for dual species atom interferometry in space. This contribution focuses on the mission goals, simulation results of quantum mixture density profiles, transport of mixtures considering gravitational effects and preparation of mixtures using delta-kick cooling for further reduction of the momentum spread. These techniques are important prerequisites to perform EEP tests with BECs created on an atom chip under microgravity. The MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number: 50WP1431.

Q 22.4 Tue 16:30 Empore Lichthof

Non-equilibrium steady states of driven dissipative quantum gases beyond ultraweak coupling — •Adrian Köhler, André Eckardt, and Alexander Schnell — TU Berlin, Berlin, Deutschland

The microscopic description of ideal quantum gases in presence of a finite coupling to a heat bath poses a theoretical challenge. Even though the system itself is non-interacting, the system-bath coupling is cubic in the field operators making the problem interacting. As a first step, we study the mean-field dynamics of the single-particle density matrix under the Redfield quantum master equation. We find that typical steady-state solvers converge only in a very limited parameter regime, forcing one to rely on numerically more costly time-integration. We also discuss approaches to overcome this problem using perturbation theory in the coupling strength. We apply our approach to a Bose gas coupled to two baths of different temperature, for which in the regime of ultraweak coupling Bose condensation is predicted also in cases, where both bath temperatures lie well above the equilibrium crtitical temperature [PRL 119, 140602]. In the regime of finite coupling, we find that steady-state solutions of the Redfield quantum master equation form a condensate in the ground state.

Q 22.5 Tue 16:30 Empore Lichthof

Compressibility and the equation of state of an optical quantum gas in a box — •Leon Espert Miranda, Erik Busley, Andreas Redmann, Christian Kurtscheid, Kirankumar Karkihalli Umesh, Frank Vewinger, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Germany

The compressibility of a medium, quantifying its response to mechanical perturbations, is a fundamental quantity determined by the equation of state. For gases of material particles, studies of the mechanical response are well established, in fields from classical thermodynamics to cold atomic quantum gases. Here we demonstrate a measurement of the equation of state as well as the compressibility of a homogeneously trapped two-dimensional quantum gas of light inside a nanostructured dye-filled optical microcavity. Upon reaching quantum degeneracy we observe signatures of Bose-Einstein condensation in the finite-size system, causing a sharp increase of the density response to an external force, hinting at the infinite compressibility of the uniform two-dimensional Bose gas.

Q 22.6 Tue 16:30 Empore Lichthof

Bath engineering in atomic quantum gas mixtures — •Lorenz Wanckel, Alexander Schnell, and André Eckardt — Technische Universität Berlin, Institut für Theoretische Physik, 10623 Berlin, Germany

Periodically driven isolated quantum systems usually heat up over time to the infinite temperature state via resonant excitation. For open driven systems, which are allowed to dissipate energy into a thermal bath, there is a non-equilibrium steady state, which is determined by the details of driving and dissipation. Appropriate engineering of the system and bath parameters can lead to interesting system states. We investigate theoretically a one-dimensional ideal Bose gas, which is locally driven and globally coupled to a three dimensional thermal bath, given by a second species of atoms. We explore the spectral densities for various baths, fermionic and bosonic, and show that the interplay of driving and dissipation can induce Bose condensation in the ground state or some excited state at bath temperatures well above the crossover temperature, at which Bose condensation would occur as a finite size effect in the system. Our analysis, which is based on a microscopic model that is solved using Floquet-Born-Markov theory, can be used to probe the results in a realistic experiment.

Q 22.7 Tue 16:30 Empore Lichthof

Vortex Motion and Annihilation in Holographic Superfluids — Paul Wittmer[1,2], Christian-Marcel Schmied[2,3], •Martin Zboron[3], Thomas Gasenzer[1,2,3], and Carlo Ewerz[1,2] — [1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

Gauge-gravity duality establishes a connection between strongly correlated quantum systems and higher-dimensional gravitational theories at weak coupling. In general, finding the quantitative parameters of the quantum system thus described is challenging. We numerically simulate dynamics of generic vortex configurations in the holographic superfluid in two and in three spatial dimensions and match to these the corresponding dynamics resulting from the dissipative Gross-Pitaevskii equation. Excellent agreement between the vortex core profiles and their trajectories in both frameworks is found, both in two and three dimensions. Comparing our results to phenomenological equations for point- and line-like vortices allows us to extract friction parameters of the holographic superfluid. The parameter values suggest the applicability of two-dimensional holographic vortex dynamics to strongly coupled Bose gases or Helium at temperatures in the Kelvin range, effectively enabling experimental tests of holographic far-from-equilibrium dynamics.

Q 22.8 Tue 16:30 Empore Lichthof

Dynamical phases in an atom-cavity system: From time crystals to dark states — •Jim Skulte[1,2], Phatthamon Kongkhambut[1], Richelle J.L. Tuquero[3], Hans Kessler[1], Jayson G. Cosme[3], Andreas Hemmerich[1,2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany. — [3]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

Ultracold atoms placed inside a high finesse optical cavity, which are continuously pumped or periodically driven display very rich phase diagrams. We specifically discover non-equilibrium phases called time crystals emerging in this platform. Time crystals are classified as discrete or continuous depending on whether they spontaneously break discrete or continuous time translation symmetry. First, we study an

emergent limit cycle phase for a blue-detuned pump and show that this state can be classified as a continuous time crystal [1]. On the other hand, phase shaking of the pump beam can be used to map the system onto a parametrically driven dissipative three-level Dicke model [2]. For weak driving this leads an incommensurate time crystal, while for strong driving this state is only metastable and relaxes into a dark state [3]. [1] P. Kongkhambut et al., Science 377, 6606 (2022)
[2] J. Skulte et al., PRA 127, 253601 (2021)
[3] J. Skulte et al., arXiv:2209.03342 (2022)

Q 22.9 Tue 16:30 Empore Lichthof

Dynamical light-matter phases in an atom-cavity platform — •Phatthamon Kongkhambut[1], Hans Kessler[1], Jim Skulte[1], Ludwig Mathey[1], Jayson G. Cosme[2], and Andreas Hemmerich[1] — [1]Institut für Laser-Physik, Universität Hamburg — [2]National Institute of Physics, University of the Philippines

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the very small field decay rate ($\kappa/2\pi$ = 3.5 kHz), which is in the order of the recoil frequency ($\omega_{rec}/2\pi$ = 3.6 kHz). This leads to a unique situation where cavity field evolves with the same time scale as the atomic density distribution. Pumping the system with a steady state light field, red detuned with respect to the atomic resonance, the Dicke model is implemented including the self-organisation phase transition. Starting in the self-ordered superradinat phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetry-broken states [1]. Modulation of the phase of the pump field give rise to an incommensurate time crystalline behaviour [2]. For a blue-detuned pump light with respect to the atomic resonance, we observe limit cycles. Since the used pump protocol is time-independent, the emergence of a limit cycle phase heralds the breaking of continuous time-translation symmetry[3]. [1] H. Keßler et al., PRL 127, 043602 (2021), [2] P. Kongkhambut et al., PRL 127, 253601 (2021), [3] P. Kongkhambut et al., Science 377, 6606 (2022).

Q 22.10 Tue 16:30 Empore Lichthof

Vortex splitting, not stirring — •Lars Arne Schäfer — Institut für angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, D-64289 Darmstadt

We examine Bose-Hubbard ring systems in two dimensional configurable arrays of dipole potentials [1]. This is an example for an atomtronics device [2]. Here, an individual small ring with few sites and few particles acts like an artificial atom with a clearly resolved spectrum. We analyze the single-particle spectrum in terms of eigenfunctions of the Hamiltonian operator as well as the discrete translational symmetry of the 1-D lattice. Coupling two or more of such systems creates a quantum network.

It is experimentally feasible to create controllable time-dependent on-site optical potentials by means of electronic wavefront manipulation (DMD, SLD) and microlens arrays. In contrast to phase imprinting, we study two counter-propagating lattice potentials to create persistent currents or vortices of few bosons. This is in analogy to Bragg matter-wave splitters for linear momentum states [3]. Finally, we study the efficiency for pulsed splitting of many-body states into vortex-anti-vortex pairs.

[1] M. R. Sturm et al., Phys. Rev. A, **95**, 063625 (2017)
[2] R. Dumke et al., J. Opt., **18**, 093001 (2016)
[3] A. Neumann, M. Gebbe, and R. Walser, Phys. Rev. A, **103**, 043306 (2021)

Q 22.11 Tue 16:30 Empore Lichthof

Constructing a matter-wave microscope for lithium atoms featuring a highly tunable optical lattice — •Mathis Fischer, Nora Bidzinski, Justus Brüggenjürgen, Luca Asteria, Henrik Zahn, Marcel Kosch, Klaus Sengstock, and Christof Weitenberg — Institut für Laserphysik, Universität Hamburg, Germany

Imaging is crucial for gaining insight into physical systems. In the case of ultracold atoms in optical lattices, quantum gas microscopes have revolutionized the access to quantum many-body systems by detecting single particles. However they are limited to investigating 2D systems and are technically demanding. We have developed the novel technique of matter-wave microscopy that allows for a magnification of an atomic sample that can then be imaged using standard absorption imaging techniques. This enables sub-lattice resolution of single lattice-sites and imaging of coherence properties in 3D systems even with rather low-resolution imaging setups. In addition, we have introduced a novel lattice setup with a highly stable and dynamically controllable lattice geometry. The interference of three laser beams is suppressed by detuning their frequencies and then pairwisely reestablished by imprinting sidebands onto each beam. This setup allows us to use the same beams as a dipole trap, which we can employ as a confining potential during matter-wave optics and for creating BECs. We are currently upgrading our lithium machine to combine these developments with the precise control over the interaction strength using Feshbach resonances. In the future, we plan to implement single particle sensitive imaging to study intriguing many-body systems.

Q 22.12 Tue 16:30 Empore Lichthof

Towards a K39 Quantum gas microscope — •Ruben Erlenstedt[1], Scott Hubele[1,2], Martin Schlederer[1,2], Alexandra Mozdzen[1,2], Guillaume Salomon[1,2], and Henning Moritz[1,2] — [1]Institut für Laserphysik, Universität Hamburg, Hamburg, Deutschland — [2]Cluster of Excellence: CUI - Advanced Imaging of Matter

Ultracold atoms offer unique opportunities for studying quantum magnetism due to the tunability of the interaction strength as well as the tunneling parameters in optical lattices. In recent years, we have built a setup able to cool 39K atoms to Bose-Einstein condensation and to image them with a high resolution (NA=0.7) using an in-vacuo objective. Together with a brief overview of the machine, I will present the progress of my master's thesis towards realising the 'science' optical lattices that will be used for the realization of Hubbard models as well as near resonant 'pinning' optical lattices that will be used for single atom sensitive imaging.

Q 22.13 Tue 16:30 Empore Lichthof

A functional renormalization group approach to non-thermal fixed points in an ultracold Bose gas — •Aleksandr N. Mikheev[1,2], Jan M. Pawlowski[2,3], and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]ExtreMe Matter Institute EMMI, GSI, Planckstraße 1, 64291 Darmstadt, Germany

Classification and understanding of scaling solutions in closed quantum systems far from thermal equilibrium, known as non-thermal fixed points, is one of the open problems in non-equilibrium quantum many-body theory. The usual method involves searching for possible self-similar solutions to a (non-perturbative) evolution equation, e.g., Boltzmann or Kadanoff-Baym, starting from a far-from-equilibrium initial condition. We outline an alternative approach based on the correspondence between scaling and fixed points of the renormalization group. Using an ultracold Bose gas as an example we show how possible far-from-equilibrium scaling solutions can be systematically obtained by solving fixed-point renormalization-group equations.

Q 22.14 Tue 16:30 Empore Lichthof

Non-thermal fixed points of universal sine-Gordon coarsening dynamics — Philipp Heinen[1], Aleksandr N. Mikheev[1,2], Christian-Marcel Schmied[1], and •Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg

We examine coarsening of field-excitation patterns of the sine-Gordon (SG) model, in two and three spatial dimensions, identifying it as universal dynamics near non-thermal fixed points. The focus is set on the non-relativistic limit, governed by a Schrödinger-type equation with Bessel-function nonlinearity. The results of our classical statistical simulations suggest that, in contrast to wave turbulent cascades, in which the transport is local in momentum space, the coarsening is dominated by rather non-local processes corresponding to a spatial containment in position space. The scaling analysis of a kinetic equation obtained with path-integral techniques corroborates this numerical observation and suggests that the non-locality is directly related to the slowness of the scaling in space and time. Our methods, which we expect to be applicable to more general types of models, could open a long-sought path to analytically describing universality classes behind domain coarsening and phase-ordering kinetics from first principles, which are usually modelled in a near-equilibrium setting by a phenomenological diffusion-type equation in combination with conservation laws.

Q 22.15 Tue 16:30 Empore Lichthof

A sodium potassium mixture experiment for simulating polaron physics — •Jan Kilinc, Lilo Höcker, Lorenz Hahn, Joris Hoffmann, Maurus Hans, Helmut Strobel, and Markus Oberthaler — Kirchhoff Institut für Physik, Heidelberg, Deutschland

The motion of quantum impurities in a Bose-Einstein condensate (BEC) is an exemplary many-body phenomenon and a theoretical challenge especially in the regime of strong interactions between the impurities and the BEC. In the experiment such a Polaron problem can be studied using an atomic mixture, where one species realizes the impurity, while the BEC is realized with the other species. The interaction can be controlled by sizeable inter-species Feshbach resonances between sodium and potassium. In this poster, we present the current status of our sodium potassium experiment.

Q 22.16 Tue 16:30 Empore Lichthof

Non equilibrium dynamics of bosons populating higher bands of an optical lattice — •José Vargas[1,2], Car Hippler[1], and Andreas Hemmerich[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany — [2]The hamburg center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

We experimentally and theoretically explore from single-particle to many-body dynamics of a Bose-Einstein condensate populating higher bands of an optical lattice. Topics such as Bloch-oscillations along different paths over each addressable Brillouin zone of the lattice, pair-tunneling phenomenon, and re-condensation dynamics are investigated.

Q 22.17 Tue 16:30 Empore Lichthof

Effective Model of Phase Excitations in a 1D Spin-1 BEC Far from Equilibrium — Ido Siovitz, •Hannes Köper, Aleksandr Mikheev, Philipp Heinen, Stefan Lannig, Yannick Deller, Helmut Strobel, Markus Oberthaler, and Thomas Gasenzer — Kirchhof Institut für Physik, Universität Heidelberg, Heidelberg, Deutschland

The spin-1 Bose gas quenched far from equilibrium to the easy-plane shows a plethora of interesting phenomena, of which we discuss the universal spatio-temporal self-similar scaling on account of the system's vicinity to an hypothesized non-thermal fixed point. The appearance of topological excitations, such as instantons, in the transversal spin degree of freedom during the equilibration process of the condensate leads to a varying length scale, reflecting the self-similar scaling of correlations. Due to the multitude of degrees of freedom in the spin-1 BEC, the causes of the system's behavior far from equilibrium are difficult to investigate.

We present a low-energy effective field theory to describe the dynamics of the system and find the driving mechanism behind the production of such topological objects in the system. We show that the effective model presents the same self similar scaling behavior of the full spin-1 Bose gas quenched to the easy-plane phase.

Q 22.18 Tue 16:30 Empore Lichthof

Stability analysis of a periodically driven ultra-cold Bose gas — •Larissa Schwarz, Simon B. Jäger, Dimo Claude, Imke Schneider, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, D-67663, Kaiserslautern, Germany

We theoretically study the dynamics of a Bose-Einstein condensate under periodic driving of the s-wave scattering length. In this setup, we first determine the stability of the condensate using Bogoliubov theory with time-periodic modulation. We find an exponential gain in the resonant k-modes due to a parameteric amplification which leads to a rapid condensate depletion. These findings are compared with the simulation of the Gross-Pitaevskii equation which shows the formation of a density-wave pattern with the predicted k-wavevector. We extend the Bogoliubov theory by including non-linearities which result in an effective damping of the k-modes. This enables the creation of stable density-wave pattern below a critical driving strength. Moreover, above this critical driving strength we analyze simple non-quadratic models and find macroscopic and stable occupation of the resonant k-mode.

Q 22.19 Tue 16:30 Empore Lichthof

Study of a matter wave neural network — •Moritz Sträter, Niklas Käming, Klaus Sengstock, and Christof Weitenberg — Universität Hamburg (UHH), Hamburg, Deutschland

Machine learning and neural networks have proven a powerful tool for studying quantum many-body physics. Moreover, the search for new architectures and implementations of neural networks building on optical or quantum hardware is an ongoing research topic.

In this poster, we present the progress on the evaluation of a new concept of a matter-wave neural network based on the coherent coupling of momentum modes of a BEC. We study the effects of interactions on the capacity and performance of the network for example classification tasks.

In the future, we hope to find and quantify a possible advantage of coherence, non-linearities and quantum correlations for generic classification tasks, which are offered in such cold-atom hardware.

Q 22.20 Tue 16:30 Empore Lichthof

A Rydberg Atom in a BEC — •Aileen A. T. Durst and Matthew T. Eiles — Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

A Rydberg atom immersed in a BEC has many extreme interaction features. While the interaction between one of the BEC particles and its neighbors is typically short-ranged compared to other length scales in the condensate, the range of the interaction of the enormous Rydberg impurity and the surrounding bath particles is comparable to or even larger than the mean interparticle distance in the gas. Furthermore, this interaction potential is highly oscillatory and can support multiple bound states. These properties complicate the theoretical description and analysis of the Rydberg impurity, whose interaction potential cannot be replaced in general by a contact pseudopotential. We relate the Rydberg impurity problem to other impurity problems by characterizing it by the number of bound states and, equivalently, the Rydberg-bath particle scattering length, and in this way investigate in which parameter regions the system exhibits quasiparticle character.

Q 22.21 Tue 16:30 Empore Lichthof

Pattern formation and symmetry breaking in a periodically driven 2D BEC — •Nikolas Liebster[1], Marius Sparn[1], Elinor Kath[1], Maurus Hans[1], Keisuke Fujii[2], Sarah Görlitz[2], Helmut Strobel[1], Tilman Enss[2], and Markus Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Heidelberg, Germany — [2]Institut für Theoretische Physik, Heidelberg, Germany

Dynamical pattern formation is a ubiquitous phenomenon in nature, and has relevance in many fields in physics. The emergence of these patterns, as well as how symmetries are broken, remains an open field of research in quantum physical systems. By periodically driving the scattering length in a 2D potassium-39 Bose-Einstein condensate, we use parametric resonance to non-linearly populate specific momentum modes of trapped condensates. We show the emergence of randomly oriented standing waves with D4 symmetry and investigate the effects of background density distributions on the formation of patterns on the condensate.

Q 22.22 Tue 16:30 Empore Lichthof

BKT Physics for Bose Gas in 2D Box — •Til Möhnen and Axel Pelster — Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

For a two-dimensional Bose gas a Berezinskii-Kosterlitz-Thouless (BKT) transition from a superfluid phase of bound vortex-antivortex pairs to a normalfluid phase of unpaired vortices and antivortices occurs at a critical temperature, which is determined by the Nelson criterion. Here we analyze the finite-size effects of this phase transition by considering a Bose gas in a two-dimensional box. To this end we derive the underlying renomalization-group equations, which describe the screening of both the condensate and the superfluid density due to the presence of vortices and antivortices. Their solution for the parameters of the recent experiment [1] allows to quantify the impact of finite-size effects in terms of the condensate fraction. Furthermore, in the thermodynamic limit we obtain a vanishing condensate density in accordance with the Mermin-Wagner-Hohenberg theorem and we reproduce the universal BKT jump of the superfluid density at the critical temperature.

[1] P. Christodoulou et al., Nature **594**, 191 (2021)

Q 22.23 Tue 16:30 Empore Lichthof

Quantum many-body scars in a Bose-Hubbard quantum simulator — •Guoxian Su[1], Jean-Yves Desaules[2], Ana Hudomal[2,3], Aiden Daniel[2], Jad Halimeh[4], Zhen-Sheng Yuan[5], Jian-Wei Pan[5], and Zlatko Papic[2] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]School of Physics and Astronomy, University of Leeds, Leeds LS2 9JT, UK — [3]Institute of Physics Belgrade, University of Belgrade, 11080 Belgrade, Serbia — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstraße 4, D-80799 München, Germany — [5]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

Quantum many-body scarring is a phenomenon where a chaotic system prepared in special initial conditions exhibits long-lived oscillations. It presents a novel mechanism for delaying the onset of thermalization. We realize many-body scars in a Bose-Hubbard quantum simulator, which hosts an abundance of scar states. We show the slowed growth of entanglement entropy in scarred dynamics. And we investigate the ubiquity of scarring and its interaction with quantum criticality. Our work makes the resource of scarring accessible to a broad class of ultracold-atom experiments and enables the study of such phenomena in fundamental physics such as lattice gauge theories.

Q 22.24 Tue 16:30 Empore Lichthof

Entropy extraction in spinor Bose gases — •Yannick Deller[1], Moritz Reh[1], Stefan Lannig[1], Alexander Schmutz[1], David Feiz[1], Helmut Strobel[1], Martin Gärttner[1,2,3], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Physikalisches Institut, Universität Heidelberg — [3]Institut für Theoretische Physik, Universität Heidelberg

The concept of entropy plays an important role for quantum informational properties of many-body systems. However, experimental extraction of entropies is in general a challenging task due to the rapid increase of the Hilbert space dimension with system size.

As our testbed we use a spin-1 Bose-Einstein condensate of rubidium in a tight optical trap, where we routinely generate non-classical spin states by quantum dynamics after a parameter quench. With a generalized POVM protocol [1], we are able to simultaneously measure two non-commuting spin observables. We extract an entropy using distributions of experimental repetitions with a statistical estimator, that avoids binning and coarse-graining of the data. We discuss how to extend these techniques to multiwell-systems with tunnel-coupling between the wells.

[1] Kunkel et. al., PRL 123, 063603 (2019)

Q 22.25 Tue 16:30 Empore Lichthof

Observation of edge states in topological Floquet systems — •Johannes Arceri[1,2], Christoph Braun[1,2,3], Alexander Hesse[1,2], Raphaël Saint-Jalm[1,2], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, München — [2]Munich Center for Quantum Science and Technology (MCQST), München — [3]Max-Planck-Institut für Quantenoptik, Garching

Floquet engineering, i.e., periodic modulation of a system's parameters, has proven as a powerful tool for the realization of quantum systems with exotic properties that have no static analog. In particular, the so-called anomalous Floquet phase displays topological properties even if the Chern number of the bulk band vanishes. [1]

Our experimental system consists of bosonic atoms in a periodically driven honeycomb lattice. Depending on the driving parameters, several out-of-equilibrium topological phases can be realized, including an anomalous phase. [2]

As the bulk-boundary correspondence relates the properties of the bulk bands to the number of topologically protected edge modes, special interest lies in studying the behavior of them. We are investigating the real-space evolution of a wavepacket close to the edge after the release from a tightly-focused optical tweezer. This way, we observe the chiral nature of the edge state, even in the anomalous Floquet phase, thereby directly revealing the topological nature of this phase.

[1] Rudner et al., Phys. Rev. X 3, 031005 (2013)
[2] Wintersperger et al., Nat. Phys. 16, 1058-1063 (2020)

Q 22.26 Tue 16:30 Empore Lichthof

Self-oscillating pump in a topological dissipative atom-cavity system — •Justyna Stefaniak, Davide Dreon, Alexander Baumgaertner, Simon Hertlein, Xiangliang Li, Tobias Donner, and Tilman Esslinger — ETH Zurich

Pumps are transport mechanisms in which direct currents result from a cyclic evolution of the potential. As Thouless showed, the pumping process can have topological origins, when considering the motion of quantum particles in spatially and temporally periodic potentials. However, the periodic evolution that drives these pumps has always been assumed to be imparted from outside, as has been the case in the experimental systems studied so far. Here we report on an emergent mechanism for pumping in a quantum gas coupled to an optical resonator, where we observe a particle current without applying a periodic drive. The pumping potential experienced by the atoms is formed by the self-consistent cavity field interfering with the static laser field driving the atoms. Owing to dissipation, the cavity field evolves between its two quadratures, each corresponding to a different centrosymmetric crystal configuration. This self-oscillation results in a time-periodic potential analogous to that describing the transport of electrons in topological tight-binding models, such as the paradigmatic Rice*Mele pump. In the experiment, we directly follow the evolution by measuring the phase winding of the cavity field with respect to the driving field and observing the atomic motion in situ. The observed mechanism combines the dynamics of topological and open systems, and features characteristics of continuous dissipative time crystals.

Q 22.27 Tue 16:30 Empore Lichthof

Stability and vulnerability of quantum gases along the BEC-BCS crossover with quenched disorder — •Felix Lang, Jennifer Koch, Sian Barbosa, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

Quantum fluids in the so-called BEC-BCS crossover show very different microscopic pairs underlying the superfluid. This changing pairing might also change the response to perturbations of the system. We investigate the response of a molecular BEC and of a resonantly interacting Fermi gas to quenches into and out of an optical disorder potential. We monitor the response of the in-situ density distribution as well as the ability for hydrodynamic expansion, which we interpret as a measure of long-range phase coherence. Concerning the latter, we find that the BEC recovers hydrodynamic expansion after disorder quenches on time scales which can be related to energy scales in the system, whereas the unitary Fermi gas permanently loses its ability for hydrodynamics. We attribute this observation to an efficient breaking of Fermi pairs in the BEC-BCS crossover. Our work sheds light on the mechanisms underlying the superfluid pairing in interacting Fermi gases.

Q 22.28 Tue 16:30 Empore Lichthof

Report on an Erbium-Lithium machine — Florian Kiesel and •Alexandre De Martino — Eberhard Karls Universität Tübingen, Physikalisches Institut AG Groß, Auf der Morgenstelle 14, 72076 Tübingen

Ultracold Fermions cannot be cooled below about 10% of the Fermi temperature with conventional methods. Sympathetic cooling with a classical gas as an entropy reservoir may provide a new direction to overcome the current limit. Here we report on the construction and implementation of first cooling stages of a two species apparatus for the optimized symp. cooling of fermionic Li with bosonic Er. This mixture has several promising features, that have not yet been utilized for symp. cooling in any other mixture. Pushing the temperature limit is essential for the quantum simulation of strongly correlated phenomena, in particular in optical lattice.

Q 22.29 Tue 16:30 Empore Lichthof

Towards quantum simulation with strontium atoms — •Thies Plassmann[1,2], Meny Menashes[1], Leon Schaefer[1], and Guillaume Salomon[1,2] — [1]Institute of Laserphysics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg, Germany

Individually controlled ultracold atoms in programmable potential landscapes have emerged as powerful systems to explore exotic states of matter in highly-correlated quantum many-body systems.

We are currently building a new quantum simulation platform based on strontium atoms. We will report on the building of our experimental apparatus designed for short cycle times and quantum gas microscopy with single particle as well as single spin resolution. By combining optical lattices with programmable optical tweezers, we aim to study the Fermi-Hubbard model and frustrated quantum magnetism with atoms trapped in tunable 3D potentials and excited to Rydberg states.

Q 22.30 Tue 16:30 Empore Lichthof

Pair correlations in a strongly interacting two-component Fermi gas — •Manuel Jäger and Johannes Hecker Denschlag — Universität Ulm, Institut für Quantenmaterie, Deutschland

We study pair correlations in a two-component fermionic system. In particular we investigate the crossover from a Bardeen-Cooper-Schrieffer (BCS) superfluid of loosely bound Cooper pairs to a Bose-Einstein condensate (BEC) of tightly bound dimers.

For studying this system experimentally, we use a spin-balanced mixture of the two lowest ^{6}Li Zeeman states and set their interaction strength by means of the Feshbach resonance at 832 G. We then perform photoexcitation of the pairs at various temperatures and interaction strengths. The photoexcitation induces a two-body loss in our system. From analyzing the loss rate we obtain Tan's contact.

Our measurements of the two-body contact extend previously reported measurements and calculations carried out at low temperatures and at unitarity. Moreover, we find that our results above 0.5 T_F can be well described by the second order quantum virial expansion in the whole BCS-BEC crossover.

Q 22.31 Tue 16:30 Empore Lichthof

Solving the Floquet matrix for driven optical lattices — •Anna Lena Hauschild, Niklas Köming, Corinna Menz, Christof Weitenberg, and Klaus Sengstock — Institute for Laser Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Ultra cold atoms in optical lattices are a highly-tunable system for quantum emulation of many body physics in solid state systems. By changing the setup of a driven lattice system, different band structure can be studied. In our project we want to build a numerical simulation of driven lattice systems.

Here we implement the Floquet matrix method, which gives a time independent matrix working with modified copies of the base Hamiltonian. In comparison to other relevant methods such as direct time evolution of tight-binding models, the computational effort of this method is higher, but due to less approximation it is in certain cases more accurate.

For the Floquet matrix method the resulting bands will not be ordered correctly:
For intersecting bands we investigate the eigenstates and their properties around the point of intersection for the correct assignment. With this project we want so be able to find topological properties of the system and a preparation for experimental implementation.

Q 22.32 Tue 16:30 Empore Lichthof

Observation of Chiral Edge Current Suppression for Strongly Interacting Fermions in Hall Ladder Systems — •Marcel Diem[1], Tobias Petersen[1], Nejira Pintul[1], Benjamin Abeln[1], Koen Sponselee[1], Oscar Murzewitz[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institute for Laserphysics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg

Ultracold quantum gases of neutral atoms are an excellent platform for quantum simulation of Hall physics due to their ability to implement artificial gauge fields and, thus, to mimic the physics of charged particles in strong magnetic fields.

Here, we present the experimental realization of 2D Hall ladder systems in one real and one synthetic dimension and study edge currents for two ultracold fermionic ytterbium isotopes to access the role of interactions in topologically non-trivial systems. One isotope, ^{171}Yb, is non-interacting, whereas the isotope ^{173}Yb interacts repulsively. We use Raman beams to couple states with different m_F quantum number and momentum. This coupling gives rise to a strong artificial magnetic field, which is essential for the quantum Hall effect.

We observe a significant suppression of chiral edge currents for strongly interacting fermions in direct comparison to non-interacting fermions. Our work paves the way towards a better understanding of interaction effects in Hall systems.

Q 22.33 Tue 16:30 Empore Lichthof

Heidelberg Quantum Architecture: Fast and modular quantum simulation — •Tobias Hammel, Maximilian Kaiser, Vivienne Leidel, Micha Bunjes, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Heidelberg, Germany

More is always better. This is especially true when talking about the amount of data a Quantum Simulator can produce in a given time. The reason why is multi-layered, ranging from the achievable signal-to-noise ratios in data demanding experiments, over the requirements on stability during an experimental run, to aspects of ease of use and debuggability.

This experiment aims at cycle rates of up to 10 cycles per second, possibly bridging the gap to programmable, on-demand quantum simulation. The key bottlenecks that are addressed in this newly build Lithium-6 machine are a reduction of MOT loading times and a high speed thermalization into an optical dipole trap.

Modularly exchangeable optical setups including an accordion lattice, a DMD and a dark ODT paired with various characterization modules enable the simulation of a variety of physical systems. Initially, the main focus will be on the fast preparation of few-fermion systems with high fidelities.

Q 22.34 Tue 16:30 Empore Lichthof

Ultracold Fermi Gases in Box Potentials — •Rene Henke, Hauke Biss, Cesar Cabrera, Lennart Sobirey, Niclas Luick, and Henning Moritz — Institute of Laserphysics, University of Hamburg, Hamburg, Germany

In the past years, our group has managed to create homogeneous ultracold Fermi gases of ^{6}Li atoms, both in 2D and 3D trap geometries. Using Bragg spectroscopy, we measured the excitation spectrum in a momentum resolved fashion. This allowed us to observe superfluidity in the BEC-BCS crossover, to extract the superfluid gap and to compare 2D and 3D systems directly.

This poster will review some of these results and present our progress towards creating spin imbalanced mixtures in two dimensions. For these, many questions still remain unanswered, especially concerning the nature of a potential spin-polarized superfluid. One of the key questions in these systems is, whether the theoretically predicted but elusive FFLO phase exists. In this phase, fermions are theorized to form Cooper pairs with finite total momentum, due to the different Fermi momenta of spin majority and minority. More accessible open questions are whether a partially polarized superfluid can be observed in general, how stable it is and whether the transition between fully paired superfluid and partially polarized Fermi gas is of first or higher order.

Q 22.35 Tue 16:30 Empore Lichthof

Engineering of lattice models with local control in fermionic quantum gas microscopes — •Si Wang[1,2], Sarah Hirthe[1,2], Dominik Bourgund[1,2], Petar Bojovic[1,2], Thomas Chalopin[1,2], Immanuel Bloch[1,2,3], and Timon Hilker[1,2] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Ludwig Maximilian University of Munich, Munich, Germany

Quantum simulation of ultracold atoms is a powerful tool for investigating long-standing problems in condensed matter physics. Our quantum gas microscope allows us to study the exotic phases of the Fermi-Hubbard model with single-site density and spin resolution. Furthermore, our recently implemented bichromatic superlattices, together with digital micromirror devices (DMDs) in real and Fourier space, open the possibility for the realization of collisional gates with individual site control.

Q 22.36 Tue 16:30 Empore Lichthof

Towards fast, deterministic preparation of few-fermion states — •Vivienne Leidel, Tobias Hammel, Maximilian Kaiser, Micha Bunjes, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

Heidelberg Quantum Architecture is a new experiment using ultracold Lithium-6 atoms aiming to achieve rapid cycle times of under one second. Among others, our approach is to speed up the MOT loading with more available laser power enabling the use of a high flux 2D MOT as well as a modular design with micrometer reproducibility.

In particular I will present setting up a laser lock to the Lithium-6 D2 transition using a modulation transfer scheme to ensure minimal drifts in frequency. An AOM Doublepass module enabling high stability and quick setup times is presented.

Physics in lower dimension often exhibits peculiar properties. Hence, we want to fine tune the dimentionality of the system using a miniaturized accordion lattice setup. It consists of two laser beams intersecting at a tunable angle. In this way controlling the spacing between the interference fringes, and therefore the strength of the confinement of our atoms.

Q 22.37 Tue 16:30 Empore Lichthof

Emergence of collective excitations in few Fermion systems — •Johannes Reiter, Philipp Lunt, Paul Hill, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Deutschland

The emergence of collective behaviour in strongly-interacting mesoscopic systems has been a long-standing question in nuclear and cold atom physics [1,2]. Our previously established technique to deterministically prepare few Fermion systems [3] in combination with the tunability of interactions in ultracold gases allows us to address this question. However, to observe clear signatures of elementary excitations in a strongly interacting few Fermion system precise control of the optical potential is required.

We present a refined version of phase shift interferometry [5] to detect wavefront aberrations on the atoms and compensate for them using a spatial light modulator.

Building on this, we study the quadrupole mode across the BEC-BCS crossover by means of spectroscopic probes. Tuning of the interparticle interactions via a broad Feshbach resonance allows us to observe the transition from single-particle to collective excitations and varying the atom number enables us to observe the emergence of collective behaviour atom by atom.

[1] B. Mottelson *Science* 193 (4250), 287-294 (1976) [2] S. Giorgini et al. *Rev.Mod.Phys.* 80, 125 (2008) [3] F. Serwane et al. *Science* 332 (6027), 336-338 (2011) [4] L. Bayha et al. *Nature* 587.7835, 583-587 (2020) [5] P. Zupancic et al. *Optics express* 24.13, 13881-13893 (2016)

Q 22.38 Tue 16:30 Empore Lichthof

High-Resolution Optics for Modular Quantum Simulation — •Micha Bunjes[1], Tobias Hammel[1], Maximilian Kaiser[1], Philipp Preiss[2], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany) — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Heidelberg Quantum Architecture (HQA) is a new modular quantum simulator built to study the emergence of quantum phenomena in few to many-body systems.

At the heart of the custom-designed mounting structure lies a high-resolution objective acting as a fixed optical reference. To verify the performance enabled by the high numerical aperture, a modular test bench and a sub-resolution nanopore device are used to scan the point spread function of this objective across the entire field of view. In addition, the angle between the mechanical and optical axis is measured. Characterizing this system in detail enables an improved performance and counteract aberrations.

A crucial goal of HQA is an increased cycle rate, up to 10 cycles per second. To this end, a new proposal aims to accelerate the preparation of few-particle systems using a blue-detuned ring trap to increase local density and thermal scattering rate. After evaporation in this trap, the thermalization of atoms into a tight optical tweezer could be optimized. Two experimental solutions using axicons and Moiré lenses are explored.

Q 22.39 Tue 16:30 Empore Lichthof

Feshbach molecules in an orbital optical lattice — •Max Hachmann, Yann Kiefer, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We experimentally study strongly interacting degenerate Fermi gases exposed to an optical lattice. As a first benchmark, Kapitza-Dirac scattering at a 1D-optical standing wave is used to probe coherence properties of different atomic samples, including a strongly interacting Fermi gas spanning the whole BEC-BCS crossover regime. Adjusting the magnetic field in the vicinity of a Feshbach resonance allowed to create bosonic dimers formed by two fermionic 40K atoms, which are also studied in the optical lattice. Using a bipartite optical square lattice ultimately resulted in the successful selective population of higher Bloch bands, which are then analysed by means of a method resembling mass spectrometry. Binding energies and lifetimes in the second (first) Bloch band were extensively studied, where the longest lifetimes are observed at the onset of unitarity with values around 100ms(300ms). Our work prepares the stage for orbital BEC-BCS crossover physics.

Q 22.40 Tue 16:30 Empore Lichthof

Cavity-based Quantum Processor: Engineering Entanglement with Programmable Connectivity — •Marvin Holten, Stephan Roschinski, Johannes Schabbauer, Davide Natale, Giacomo Hvaring, Iris Haubold, Nicole Heider, Alexander Heiss, and Julian Leonard — Atominstiut, TU Wien, Austria

Entanglement is the fundamental resource for applications like quantum computation and communication beyond the possibilities of classical machines. Many current devices are limited to a small number of qubits if full connectivity between any two qubits independent of their spatial separation is required. Our goal is to investigate an alternative platform for quantum simulation and information processing with qubit full connectivity. The idea is to trap an array of individually addressable atoms inside an optical cavity. The photon-mediated interactions of the atoms in the cavity will enable us to introduce non-local couplings and entangling operations between any two atoms or qbits in the system. We will implement a non-destructive readout scheme that relies on injecting a few-photon field into the cavity. We plan to investigate in what ways the all-to-all connectivity of our quantum processor enables us to efficiently create highly entangled many-body ensembles, like GHZ states. Finally, we want to use the quantum processor to address longstanding questions about the thermalisation of closed quantum systems and information scrambling. With its scalability and fully programmable connectivity, our architecture has the potential to open up new pathways for a wide range of fields like quantum optimization, communication and simulation.

Q 22.41 Tue 16:30 Empore Lichthof

Preparation for the Integration of the BECCAL Laser System — •Marc Kitzmann[1], Victoria Henderson[1,2], Tim Kroh[1,2], Jakob Pohl[1,2], Matthias Schoch[1], Christoph Weise[1], Hrudya Thaivalappil Sunilkumar[1], Hamish Beck[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Achim Peters[1,2], and the BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hannover — [5]DLR-SI, Hannover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR, Braunschweig

BECCAL (Bose-Einstein Condensate and Cold Atom Laboratory) is a cold atom experiment designed for operation on the ISS. It is a DLR and NASA collaboration, built on a heritage of sounding rocket and drop tower experiments, and NASA's CAL. This multi-user facility enables the exploration of fundamental physics with Rb and K BECs and ultra-cold atoms in microgravity, facilitating prolonged timescales and ultra-low energy scales. In contrast to lab-based cold atom experiments, BECCAL must be operable without interference for three years on the ISS. To reach that goal and match the complexity of this space-based system to the stringent size, weight, and power limitations, we have to fulfill strict product assurance requirements for the laser system including higher cleanliness facilities and ESD protection. In this context, the planning and implementation of the specific lab setup and the first essential integration tests, using mock-ups, will be presented. This work is supported by the DLR with funds provided by the BMWK under grant numbers DLR 50WP1702, and 50WP2102.

Q 22.42 Tue 16:30 Empore Lichthof

A narrow linewidth and high power lasersystem for dual-species atom interferometry — •Wei Liu, Alexander Herbst, Henning Albers, Ashwin Rajagopalan, Knut Stolzenberg, Sebastian Bode, Ernst.M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The universality of free fall is one of the foundations of general relativity, which can be tested by observing the free falling of different test masses. The development of atom optics has allowed performing of quantum tests with dual-species atom interferometers. However trapping and cooling of different atomic species require lasers with different wavelengths, resulting in large and complex laser systems.

We present a new laser system capable of trapping and cooling ^{39}K, ^{41}K and ^{87}Rb. The system features high power and low maintenance by using frequency doubled C-band fiber lasers. We replace 11 external-cavity diode lasers and 8 tapered amplifiers with only 6 fiber lasers, remove all optical active components except acousto- and electro- optic modulators, and therefore simplify the laser system. On this poster we will describe the optical set up, characterisation measurements and the scheme of frequency stabilisation.

Q 22.43 Tue 16:30 Empore Lichthof

Rapid generation and number-resolved detection of spinor Rubidium Bose-Einstein condensates — Cebrail Pür[1], Mareike Hetzel[1], •Martin Quensen[1], Andreas Hüper[1,4], Jiao Geng[2,3], Wolfgang Ertmer[1,4], and Carsten Klempt[1,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]Key Laboratory of 3D Micro/Nano Fabrication and Characterization, School of Engineering, Westlake University, Zhejiang Province, China — [3]Institute of Advanced Technology, Westlake Institute for Advanced Study, Zhejiang Province, China — [4]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik (DLR-SI), Callinstraße 30b, D-30167 Hannover, Germany

High data acquisition rates and low-noise detection of ultracold neutral atoms present important challenges for high-precision atom interferometers that exploit the excellent mode quality of Bose-Einstein condensates. Here, we present a high-flux source of Rb-87 Bose-Einstein condensates combined with a number-resolving detection.

For the high-fidelity tomography of many-body quantum states in the spin degree of freedom, it is desirable to select a single mode for a number-resolving detection. We demonstrate the low-noise selection of subsamples with average atom numbers of up to 35 and their subsequent detection via accurate atom counting. The presented techniques offer an exciting path towards the creation and analysis of mesoscopic quantum states with unprecedented fidelities, and their exploitation for fundamental and metrological applications.

Q 22.44 Tue 16:30 Empore Lichthof

Light-induced correlations in ultracold dipolar atoms — •Ishan Varma, Marvin Proske, Dimitra Cristea, Nivedith Anil, and Patrick Windpassinger — Institute of Physics, JGU Mainz

Dysprosium is a fascinating candidate for studying cooperative and collective effects in dense ultra-cold media. With the largest ground-state magnetic moment of all elements in the periodic table (10 Bohr-magnetons), it offers a platform to study the effect on scattering of light due to competition between magnetic dipole-dipole interactions (DDI) and light induced correlations. In a sufficiently dense regime, the strong magnetic DDI significantly influence the propagation of light within the atomic sample. In particular, we want to look at signatures of collective light scattering phenomena like Super-radiance and Sub-radiance.

This poster reports on the progress made in generating dense samples of ultracold dysprosium atoms. We plan to optically transport atoms into a home-built science cell with high optical access. A high NA custom objective, designed and assembled in-house, will then be used to create dense atomic samples inside this cell. We evaluate the performance and discuss the installation of the custom objective in our experimental system. Further, an outlook is given on future measurements exploring collective and cooperative effects in the generated sample.

Q 22.45 Tue 16:30 Empore Lichthof

Two-dimensional grating magneto-optical trap — •Aaditya Mishra[1], Hendrik Heine[1], Joseph Muchovo[1], Julian Lemburg[1], Kai Bruns[1], Waldemar Herr[1,2], Christian Schubert[1,2], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Callinstr. 30b, D-30167 Hannover, Germany

Ultracold atoms provide exciting opportunities for precision measurements and testing fundamental physics. Two-dimensional(2D) magneto-optical traps(MOT) are advantageous in faster loading to 3D-MOTs and cooling more atoms. However, compact and power-efficient setups are essential in performing transportable experiments. In this poster, we will present a design of a two-dimensional grating magneto-optical trap (2D gMOT) requiring only a single input cooling beam. The cold atomic beam from the 2D gMOT will load atoms in a 3D gMOT implemented on an atom chip for efficient generation of BECs. This will lead to a robust, compact and efficient source of ultracold atoms that can be used in ground and space experiments.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate protection (BMWK) due to the enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS-II), DLR 50RK1978 (QCHIP) and by the German Science Foundation (DFG) under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 22.46 Tue 16:30 Empore Lichthof

Chip-Scale Quantum Gravimeter — •Julian Lemburg[1], Hendrik Heine[1], Joseph Muchovo[1], Aaditya Mishra[1], Kai Bruns[1], Ernst M. Rasel[1], Waldemar Herr[1,2], and Christian Schubert[1,2] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Institut für Satellitengeodäsie und Intertialsensorik, DLR-SI

Interferometers with Bose-Einstein condensates (BECs) enable a very precise measurement of inertial forces like gravity. Potential applications can be in ground and space-borne geodesy. A lower size, weight, and power consumption of these sensors can be realized by using atom chips. The latter enables the creation of a high flux of delta-kick collimated BECs bringing in reach an unprecendented, low measurement uncertainty.
In this poster, we will present a concept to further reduce the sensor head to about shoe-box size. With a novel atom chip combined with the implementation of a relaunch scheme, an innovative single-beam quantum gravimeter is envisaged. The further miniaturization and reduction of complexity of the sensor head are the key features to improve the transportability and ease the in-field operation of the quantum gravimeter.
This work is funded by the German Research Foundation (DFG) in the CRC 1464 "TerraQ" (Project A03) and under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 22.47 Tue 16:30 Empore Lichthof

Realization of an optical accordion for ultracold atoms — •Carole Peiffer, Felix Lang, Sian Barbosa, Jennifer Koch, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

Optical lattices, created by the interference of two or more coherent and often far-detuned laser beams, are among the most established tools used to manipulate quantum gases. One special realization, the so-called optical 'accordion', promises enhanced flexibility: when changing the angle of the two interfering beams, the lattice constant changes, allowing control over the lattice spacings over a large range of values. We aim at realizing such an accordion setup using a beamsplitter, consisting of two custom Dove-prisms, glued together by a special UV-curing epoxy, in combination with a large focusing lens. When a single beam passes through the prism pair, it is split into two parallel rays, and their distance depends on the incidental beam's. After focussing by the lens onto the atom's position , interference creates the lattice potential. I will report the planning, construction and ex-situ characterization of an optical accordion which will be used to access lower dimensions in our setup with ultracold lithium-6 atoms.

Q 22.48 Tue 16:30 Empore Lichthof

A compact and robust fiber-based laser system for cold atom experiments in microgravity — •Janina Hamann[1], Jan Simon Haase[1], Jens Kruse[2], and Carsten Klempt[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstr. 30b, 30167 Hannover

Operating atom interferometers in space opens up the possibility of a further improved phase sensitivity due to prolonged interrogation times. Especially Bose-Einstein condensates (BEC) are suitable for zero-gravity interferometry due to their well-controlled spatial mode and slow expansion rate. To prepare cold atom experiments for space operation, microgravity facilities such as the Einstein-Elevator are used for ground testing. The generation and detection of a ^{87}Rb BEC in the Einstein-Elevator requires a laser system with a high frequency stability and robustness to 5 g accelerations and vibrations. We design a fiber-based laser system with a tuneable offset frequency stabilization that uses telecom components to ensure robustness. The rugged fiber-based setup is housed in a 19" crate, where fiber-based modulators generate an adjustable offset for the 780 nm laser and additional sidebands at several GHz. An atomic reference module is used for modulation transfer spectroscopy (MTS) on ^{85}Rb. We achieve a tuneable frequency stabilization with a frequency stability of 90 kHz that can perform frequency ramps of 300 MHz in milliseconds.

Q 22.49 Tue 16:30 Empore Lichthof

Laser systems for photoassociation spectroscopy of cold Hg-atoms — •Rudolf Homm and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Cold Hg-atoms in a magneto-optical trap offer opportunities for various experiments. The two stable fermionic isotopes are interesting with regard to a new time standard based on an optical lattice clock employing the $^1S_0$ - $^3P_0$ transition at 265.6 nm. All stable isotopes can be used to form ultra-cold Hg-dimers through photoassociation in connection with vibrational cooling by applying a specific excitation scheme.

We will present our laser systems for photoassociation spectroscopy of cold Hg-atoms. The Hg-isotopes are preselected via a 2D-MOT and cooled in a 3D-MOT, while both are driven by the cooling laser system. It consists of a MOFA-Setup at 1014.8 nm followed by two consecutive frequency-doubling stages. The output power is over 900 mW at 253.7 nm without a sign of degradation in the BBO-crystal used in the second frequency-doubling stage, due to a cavity with elliptical focus in the crystal [1].

The setting of the spectroscopy laser system is quite similar to the cooling laser, while the aims are different. The output power needs to be only several dozen mW at the target wavelength of 254.1 nm, but the frequency tuning range of the system has to be much higher. We will report on the status of the experiments.

[1] Preißler, D., *et al.*, *Applied Physics B* **125** (2019): 220

Q 22.50 Tue 16:30 Empore Lichthof

Ultracold Bose gases in temporally and spatially modulated Potentials — •Marco Decker, Erik Bernhart, Marvin Röhrle, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

We investigate Bose-Einstein condensates in spatially and temporally modulated potentials. This allows us to study quantum transport phenomena and quantum scattering problems.

To extend discrete models to continuum physics, we shift from lattice potentials to localized potentials in an optical trap. The potentials are projected onto the atoms with an objective inside the vacuum chamber, which is also used for absorption imaging. The atomic cloud can additionally be imaged via an electron column with high spatial resolution. Additionally, implementing two blue-detuned light sheets, we can furthermore change the trap geometry from 3D to quasi 2D.

Future studies will include time-dependent barriers and local dissipation via the electron column.

Q 22.51 Tue 16:30 Empore Lichthof

Sideband Thermometry on Ion Crystals — •Ivan Vybornyi[1], Laura Dreissen[2], Daniel Vadlejch[2], Tanja Mehlstäubler[2], and Klemens Hammerer[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2,30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100,308116 Braunschweig, Germany

Crystals of ultracold trapped ions reach sizes of hundreds of individual particles and require high level of control over their motional temperature to account for the second-order Doppler shift in clocks and implement high-fidelity quantum gates in quantum computers. The existing thermometry tools fail to provide an accurate temperature estimation for large ground-state cooled crystals, either focusing only on the symmetric c.o.m. mode of motion or neglecting the involved spin-spin correlations between the ions.

To resolve the thermometry large-N bottleneck, we consider crystal many-body dynamics arising when motional sideband transitions are driven in a near ground-state regime, which is a widely used approach in thermometry of a single ion. To gain some valuable insights on the sideband thermometry method, we also address the single ion case and study it from the Fisher Information prospective.

Extending the approach further, we account for entanglement created between the ions in a crystal to derive a new reliable temperature estimator, insensitive to the number of ions, and field-test in experiments with 4- and 19-ion crystals done by colleagues from PTB and Innsbruck.

Q 22.52 Tue 16:30 Empore Lichthof

Invisible flat bands on a topological chiral edge — •Youjiang Xu, Irakli Titvinidze, and Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, Germany

We prove that invisible bands associated with zeros of the single-particle Green*s function exist ubiquitously at topological interfaces of 2D Chern insulators, dual to the chiral edge/domain-wall modes. We verify this statement in a repulsive Hubbard model with a topological flat band, using real-space dynamical mean-field theory to study the domain walls of its ferromagnetic ground state. Moreover, our numerical results show that the chiral modes are split into branches due to the interaction, and that the branches are connected by invisible flat bands. Our work provides deeper insight into interacting topological systems. (preprint: arXiv:2204.11946)

Q 22.53 Tue 16:30 Empore Lichthof

Optical simulations for highly sensitive atom interferometry — •Gabriel Müller, Stefan Seckmeyer, and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Using atom interferometers as highly sensitive quantum sensors requires both precise understanding and control of their main building block: atom light interactions. To properly describe the atom light interactions we need an accurate description of the laser-driven light fields. Distortions of ideal Gaussian beams on their path to the atoms can cause several disturbing effects. For example, the occurrence of asymmetric optical dipole forces acting on the atoms can cause a loss of contrast. Here, we build an optical simulation tool using Fast-Fourier-transform beam propagation methods to take into account arbitrarily shaped obstacles. We compare these results, on small scales, to solutions of Maxwell's equations finding good agreement. Finally, we apply our optical simulations to guide the design of the next unit of NASA's Earth-orbiting Cold Atom Lab and DESIRE, a microgravity experiment searching for Dark Energy.

This work is supported by DLR funds from the BMWi (50WM2245A-CAL-II and 50WM2253A-(AI)^2).

Q 22.54 Tue 16:30 Empore Lichthof

Green's functions formulation of Floquet topological invariants — •Marcus Meschede, Helena Drüeke, and Dieter Bauer — University of Rostock

Floquet topological insulators (FTIs) allow for topological protection through their time evolution as opposed to static topological insulators, which are only protected by their band topology. FTIs have become ubiquitous in the pursuit of realizing new phases of matter. In general, the momentum-dependent quasi-energy spectrum of single-particle time evolution operators or, equivalently, Floquet Hamiltonians is used to classify the band topology. In the presence of many-particle interactions, this single-particle picture breaks down. In order to overcome this issue, topological invariants of static systems have been formulated through their single-particle Green's functions. [1,2] We expand on this work by calculating Floquet topological invariants through their Floquet Green's function. As there is much experimental work on realizing FTIs, we hope to provide another tool to determine the topological properties of these systems through their bulk spectral function.

[1] Gurarie, V. "Single-Particle Green*s Functions and Interacting Topological Insulators." Physical Review B 83, 085426 (2011).

[2] He, Yuan-Yao, Han-Qing Wu, Zi Yang Meng, and Zhong-Yi Lu. "Topological Invariants for Interacting Topological Insulators. I. Efficient Numerical Evaluation Scheme and Implementations." Physical Review B 93, 195163 (2016)

Q 22.55 Tue 16:30 Empore Lichthof

Light-induced correlations in cold dysprosium atoms — •Nivedith Anil, Marvin Proske, Ishan Varma, Dimitra Cristea, and Patrick Windpassinger — Institut für Physik, JGU Mainz

We intend to study light-matter interactions to explore the effect of magnet dipole-dipole interactions in highly dense samples of atoms exhibiting large permanent magnetic dipole moments. When the average interatomic distances are smaller than the wavelength of the scattering light, strong electric and magnetic dipole-dipole interactions give rise to collective light-scattering phenomena in the spectral and temporal domains. With the largest ground-state magnetic moment in the periodic table (10 Bohr-magneton), dysprosium is the perfect candidate for these experiments.

This poster reports on our progress in generating extremely dense ultracold atomic dysprosium clouds. We present our method to optically transport the atoms into a home-built science cell using a high-precision air-bearing translation stage. A custom-built high NA objective will re-trap the transported atoms in a tightly focussed microscopic optical dipole trap. Further, we discuss the design of a magnetic field system, which allows for highly precise magnetic field control and the ability to tune the contact interactions between the dysprosium atoms.

Q 22.56 Tue 16:30 Empore Lichthof

Borromean states in a one-dimensional three-body system — •Tobias Schnurrenberger[1], Lucas Happ[2], and Maxim Efremov[1]

— [1]German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany — [2]RIKEN Nishina Center, Strangeness Nuclear Physics Laboratory, Wako 351-0198, Japan

We explore the Borromean states of a one-dimensional quantum three-body system composed of two identical heavy particles and a different particle of smaller mass. There is no heavy-heavy interaction potential and no bound state supported by the heavy-light one. To determine the parameters of the heavy-light potential for which the Borromean states may exist, we apply and compare two approaches: (i) the Born-Oppenheimer approximation, being usually valid for a large mass ratio between heavy and light particles, and (ii) the Faddeev equations, being exact for any mass ratio.

Q 22.57 Tue 16:30 Empore Lichthof

Snapshot-based detection of hidden off-diagonal long-range order on lattices — Fabian Pauw[1], •Felix A. Palm[1], Annabelle Bohrdt[2], Sebastian Paeckel[1], and Fabian Grusdt[1] — [1]LMU Munich & MCQST, Munich, Germany — [2]Harvard University & ITAMP, Cambridge (MA), USA

Revealing the existence of hidden off-diagonal long range order is believed to be a promising avenue towards identifying and characterizing topological order. In continuum fractional quantum Hall systems this can be accomplished by attaching gauge flux tubes onto the particles. Following the recent advances of cold atom experiments in optical lattices, probing this hidden, non-local order parameter with Fock-basis snapshots for lattice analogs is now within reach. Here, we demonstrate the existence of hidden off-diagonal long range order in quasi two-dimensional lattices in the $\nu = 1/2$-groundstate of the experimentally realistic isotropic Hofstadter-Bose-Hubbard model. To this end, we provide a MPS-driven, hybrid one and two-site snapshot procedure to sample the one-particle reduced density matrix and all particle positions simultaneously, emulating an experimentally feasible protocol. We present strong numerical indications for the emergence of an algebraic decay and discuss the resolution achievable using only few snapshots.

Q 22.58 Tue 16:30 Empore Lichthof

Few fermions in an arbitrary potential — •Jonas Herkel, Sandra Brandstetter, Carl Heintze, Keerthan Subramanian, and Selim Jochim — Physikalisches Institut, University Heidelberg, Germany

Fermionic quantum systems with a tuneable atom number have proven to be a viable platform for exploring the emergence of many-body phenomena. In our experiment we are able to prepare a fermionic few-body system of 6Li atoms by spilling a two dimensional trap.

We use two different matter wave optic techniques to achieve single atom resolution. Combined with our spin resolved imaging technique, this allows for the examination of correlations between atoms in different spin states. A non interacting expansion maps the initial momenta to real space. For real space imaging we use a technique similar to (1), which combines the evolution in two harmonic potentials with different trapping frequencies, to magnify the spatial distribution. These imaging techniques allows us to explore hydrodynamic behavior of the few body limit.

We plan to setup a digital-micro-mirror-device (DMD) in a compact and modular way. The DMD will allow us to form nearly arbitrary uniform potentials, with a blue detuned laser. One possible application is a double box to explore the transport physics of a small number of atoms. The fast dynamics of the DMD additionaly allows for dynamic potentials, which could be utilized to explore collectivity of few atoms.
(1) Asteria et al. Nature 599, 571*575 (2021).
https://doi.org/10.1038/s41586-021-04011-2

Q 22.59 Tue 16:30 Empore Lichthof

Commercial Off-The-Shelf Replicate of the BECCAL Laser System for Cold Atom Experiments on the ISS — •Hamish Beck[1], Victoria Henderson[1,2], Tim Kroh[1,2], Jakob Pohl[1,2], Matthias Schoch[1], Christoph Weise[1], Hrudya Thaivalappil Sunilkumar[1], Marc Kitzmann[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Achim Peters[1,2], and the BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hannover — [5]DLR-SI, Hannover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR, Braunschweig

BECCAL (Bose-Einstein Condensate–Cold Atom Laboratory) is a cold atom experiment designed for operation on-board the ISS. This DLR and NASA collaboration builds upon the heritage of sounding rocket and drop tower experiments as well as NASA's CAL. Fundamental physics with Rb and K BECs and ultra-cold atoms will be explored in this multi-user facility in microgravity, providing prolonged timescales and ultra-low energy scales compared to those achievable on earth. A ground-based replicate of the apparatus must also be built to support the operation of the flying experiment. The size, weight, and power constraints of such a Ground-based Test Bed (GTB) are relaxed, and so the laser system may be made from Commercial Off-The-Shelf (COTS) components. The design of this GTB laser system will be presented alongside the design of the flight hardware for a direct comparison.

This work is supported by the DLR with funds provided by the BMWK under grant numbers DLR 50WP1702, and 50WP2102.

Q 22.60 Tue 16:30 Empore Lichthof

Cryogenic system for Rydberg quantum optics — •Cedric Wind, Julia Gamper, Valerie Mauth, Florian Pausewang, Tore Homeyer, Hannes Busche, and Sebastian Hofferberth — Institute of Applied Physics, Bonn, Germany

Thanks to their strong interactions, Rydberg atoms are a key to neutral atom quantum simulation and computing or to implement nonlinear single photon devices such as single photon sources, optical transistors or photon-photon gates based on Rydberg quantum optics. Rydberg atoms also offer electric transitions over a wide range of the electromagnetic spectrum ranging from optical transitions close to the ground state to strong microwave transitions between Rydberg states. These properties make them an attractive ingredient to implement hybrid quantum systems interfacing optical and microwave frequencies.

Here, we present our design and construction of a cryogenic setup producing ultracold atoms in a 4K-environment to implement hybrid systems including Rydberg atoms. The system combines a closed-cycle cryostat with vibration isolation and an ultracold-atom production setup starting with a room-temperature magneto-optical trap and a magnetic transport into the cryo-region. In particular, the whole system is designed to enable fast exchange and cooling of samples in the experiment region to 4 K which can include electromechanical oscillators, superconducting circuits, or integrated photonic circuits. The cryostat promises a strong suppression of black-body induced Rydberg decay and improved vacuum conditions thanks to cryo-pumping that eliminates the need to bake the system when changing samples.

Q 22.61 Tue 16:30 Empore Lichthof

Rydberg superatoms for waveguide QED — •Nina Stiesdal[1], Lukas Ahlheit[1], Anna Spier[1], Jan de Haan[1], Kevin Kleinbeck[2], Jan Kumlin[3], Hans-Peter Büchler[2], and Sebastian Hofferbert[1] — [1]IAP, University of Bonn — [2]ITP3, University of Stuttgart — [3]CCQ, Aarhus University

Waveguide-systems where quantum emitters are strongly coupled to a single propagating light mode offer an interesting platform for quantum nonlinear optics. We work towards realizing a cascaded system in free space by using Rydberg superatoms - single Rydberg excitations in individual atomic ensembles smaller than the Rydberg blockade-volume - as directional effective two-level systems.

On this poster we show our setup implementing a one-dimensional chain of Rydberg superatoms with low internal dephasing. We employ a double magic-wavelength optical lattice to pin atoms during optical experiments using Rydberg states and thus reduce motional dephasing of the collective excitation. We further show our interferometer setup for obtaining phase information about the photons to perform full state tomography of outgoing multi-photon pulses to characterize the effective photon-photon interaction mediated by the superatom chain.

Q 22.62 Tue 16:30 Empore Lichthof

Rydberg quantum optics in ultracold Ytterbium gases — •Thilina Muthu-arachchige[1], Xin Wang[1], Jonas Ceislick[1], Katherina Gillen[2], and Sebastian Hofferberth[1] — [1]Institute for Applied Physics, University of Bonn, Germany — [2]California Polytechnic State University, San Luis Obispo, USA

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons. Demonstrations of photon-photon gates or multi-photon bound states based on this concept have so far exclusively employed ultracold alkali atoms. Two-valence electron species, such as ytterbium, offer unique novel features such as narrow-linewidth laser-cooling, optical detection and ionization or long-lived nuclear-spin memory states.

On this poster, we present our ultracold ytterbium setup designed for few-photon Rydberg quantum optics experiments. The system is optimized for fast production of large, thermal ytterbium samples to study the interactions between a large number of Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. Specifically, we discuss our two-chamber 2d/3d two-color MOT setup, our implementation of narrowline SWAP MOT techniques and Rydberg excitation of optically trapped Ytterbium atoms.

Q 22.63 Tue 16:30 Empore Lichthof

Level statistics and entanglement entropy of Rydberg dressed bosons in a triple-well potential — •Tianyi Yan[1], Matthew Collins[1], Rejish Nath[2], and Weibin Li[1] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [2]Department of Physics, Indian Institute of Science Education and Research, Dr. Homi Bhabha Road, Pune-411008, Maharashtra, India

We study signatures of quantum chaos of Rydberg dressed bosonic atoms in a three-well potential. Dynamics of the atoms are governed by an extended Bose-Hubbard model (EBHM) where long-range nearest-neighbor and next-nearest-neighbor interactions are induced by laser coupling the ground state to Rydberg state. We analyze level statistics of the EBHM with N atoms through numerical diagonalization. In the presence of a tilting potential, the level statistics is a Poissonian distribution when the dressed interaction is weak. It becomes a Wigner-Dyson distribution by increasing the interaction strength, signifying the emergence of quantum chaos. A hybrid distribution is obtained when the dressed interaction is much stronger than the hopping rate. Using Fock basis, we further calculate dynamical evolution of the entanglement entropy. The maximal value (upper bound) of the entanglement entropy is found to be $\ln(N+1)$. The maximum of the time-averaged entanglement entropy appears when the chaos is strong. The location of the maximum as a function of the dressed interaction and tilting potential is independent of N when N is large.

Q 22.64 Tue 16:30 Empore Lichthof

Chiral Rydberg State in cold atoms for chiral sensing. — Stefan Aull[1], Steffen Giesen[2], •Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Institut für Physik, Experimentalphysik I , Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel — [2]2Fb. 15 - Chemie, Hans- Meerwein-Straße 4, 35032 Marburg — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

It has been shown theoretically [1] that by combining a superposition of Hydrogenic wavefunctions in combination with appropriately adjusted phases, the resulting electronic state can show chiral properties. We are proposing a protocol for experimentally creating those states in a ultra-cold cloud of Rubidium atoms by exciting into a circular Rydberg state and subsequently generating a superposition of different states of almost maximum ℓ and m_ℓ. The results are aimed to be used for chiral discrimination [2] of molecules. Optimized parameters will be determined to maximize the chiral sensitivity.

[1] A. Ordonez, O. Smirnova. Propensity rules in photoelectron circular dichroism in chiral molecules. I. Chiral hydrogen, Phys. Rev. A 99, 043416 (2019)

[2] S Y Buhmann et al, Quantum sensing protocol for motionally chiral Rydberg atoms, New J. Phys. 23, 083040 (2021)

Q 22.65 Tue 16:30 Empore Lichthof

RF spectroscopy of ultracold Rydberg atoms and molecules — Edward Treu-Painter, Martin Trautmann, and •Johannes Deiglmayr — Universität Leipzig, Germany

RF Spectroscopy of Rydberg atoms is an established tool to determine the hyperfine structure [1] and quantum defects [2] of Rydberg atoms. We have recently extended this to the spectroscopy of long-range Rydberg molecules [3].

Here we present recent results on the characterization of the $n^2\mathrm{D}_J$ Rydberg series of Cesium using RF spectroscopy that yielded a new set of quantum defect parameters for the two fine-structure components with highly improved precision and accuracy. We will also present experimental and theoretical results on long-range Rydberg molecules correlated to $n^2\mathrm{D}_J$ Rydberg states that we probe by RF spectroscopy.

[1] H. Saßmannshausen, F. Merkt, and J. Deiglmayr, *High-resolution spectroscopy of Rydberg states in an ultracold cesium gas*, Phys. Rev. A **87(3)**, 032519 (2013) [2] J. Deiglmayr *et al.*, *Precision measurement of the ionization energy of Cs I*, Phys. Rev. A **93(1)**, 013424 (2016); M. Peper *et al*, *Precision measurement of the ionization energy and quantum defects of* ^{39}K *I*, Phys. Rev. A **100(1)**, 012501 (2019) [3] M. Peper and J. Deiglmayr, *Photodissociation of long-range Rydberg molecules*, Phys. Rev. A **102(6)**, 062819 (2020); M. Peper, and J. Deiglmayr, *Heteronuclear Long-Range Rydberg Molecules*, Phys. Rev. Lett. **126(1)**, 013001 (2021)

Q 22.66 Tue 16:30 Empore Lichthof

Stability of quantum degenerate fermionic polar molecules with and without microwave shielding — •Antun Balaž[1] and Axel Pelster[2] — [1]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Department of Physics, Technical University of Kaiserslautern, Germany

A stabilization of a fermionic molecular gas towards collapse in attractive head-to-tail collisions and its evaporative cooling below the Fermi temperature has so far been achieved in two ways. Either a strong dc electric field is applied to confine the molecular motion to 2D [1] or inelastic collisions in 3D are strongly suppressed by applying a circularly polarized microwave field [2]. Here we use a Hartree-Fock mean-field theory [3,4] in order to determine the 3D properties of quantum degenerate fermionic molecules. In particular, we compare the stability diagrams occurring with and without microwave shielding, where a dipole-dipole interaction with negative and positive sign is present. In case when the orientation of the electric dipoles with respect to the trap axes is unknown, we outline how to reconstruct it from time-of-flight absorption measurements.

[1] G. Valtolina et al., Nature **588**, 239 (2020).
[2] A. Schindewolf et al., Nature **607**, 677 (2022).
[3] V. Veljić et al., New J. Phys. **20**, 093016 (2018).
[4] V. Veljić et al., Phys. Rev. Research **1**, 012009(R) (2019).

Q 22.67 Tue 16:30 Empore Lichthof

Creating auto-ponderomotive potentials for electron beam manipulation — •Franz Schmidt-Kaler, Michael Seidling, Robert Zimmermann, Nils Bode, and Peter Hommelhoff — Friedrich Alexander Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Advances in complex free electron beam manipulation are shown to be possible based on planar chips using electrostatic fields. In the co-moving frame of the electrons these static fields transform into alternating forces creating an engineered auto-ponderomotive potential. This confining pseudopotential resembles the one of a radiofrequency-driven Paul trap. Well-designed electrode layouts enable electron beam splitting and curved guiding, which we demonstrated. The applied electron energies range from a few eV to 1.7 keV (splitting) and 9.5 keV (guiding) permitting integration into standard scanning electron microscopes to allow entirely new electron control. Furthermore, we measured the first a-q stable parameter space demonstrating the similarity of our APE design's to Paul trap's potentials.

Q 22.68 Tue 16:30 Empore Lichthof

Coulomb effects in ultrashort few electron pulses — •Stefan Meier, Jonas Heimerl, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Most electron-based microscopy methods benefit from a high spatial coherence of the electron beam used. The smaller the electron source, the higher the spatial coherence, allowing, for example, particularly small foci in the electron microscope. Tungsten needle tips represent such highly coherent electron sources, with effective source sizes in the subnanometer range. Moreover, electron emission can be triggered by femtosecond short laser pulses, providing a source of ultrashort electron pulses. In this contribution, we investigate the transverse coherence properties of such a pulsed source as a function of the emitted current [1]. We show that the effective source size grows due to Coulomb effects already for one emitted electron per pulse on average. In a next step, we consider by postselection only the electron pulses in which two electrons have been emitted. In this case we observe strong energy anticorrelation between both electrons due to the extreme spatial and temporal confinement of the electrons during emission. We report on the current status of these measurements and the implications that arise from them.

[1] S. Meier and P. Hommelhoff, ACS Photonics **9**, 3083 (2022)

Q 22.69 Tue 16:30 Empore Lichthof

Coherent Light-Electron Interaction in an SEM — •Maxim Sirotin, Tomáš Chlouba, Roy Shiloh, and Peter Hommelhoff

— Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

The coherent interaction of light and free electrons was experimentally demonstrated over a decade ago in a transmission electron microscope (TEM) in the form of photon-induced near-field electron microscopy (PINEM). Until today, it has found many fundamental scientific applications such as attosecond quantum coherent control, free electron quantum state generation and photon statistics reconstruction. So far, all PINEM experiments used ultrafast TEMs rather than scanning electron microscopes (SEM), mainly because the required high-resolution spectrometer is not commercially available. However, SEMs allow access to the yet unexplored subrelativistic energy range from ∼0.5 to 30 keV which provides potentially higher electron-light coupling efficiency. Also, SEMs offer spacious and easily-configurable experimental chambers for extended optical setups, potentially boasting thousands of photon-electron interaction sites. We built a compact magnetic high-resolution electron spectrometer and experimentally demonstrated the quantum coherent coupling between electrons and optical nearfields in an SEM at unprecedentedly low, sub-relativistic energies [1]. This demonstration of PINEM in an SEM opens a new avenue to fundamental research in electron-photon quantum interactions.

[1] R. Shiloh, T. Chlouba, and P. Hommelhoff, Physical Review Letters **128**, 235301 (2022)

Q 22.70 Tue 16:30 Empore Lichthof

Simulation of expanding BECs and matter-wave lensing — •Nico Schwersenz and Albert Roura — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm

The extended microgravity conditions afforded by cold-atom experiments in space enable free-evolution times of many seconds, which can be exploited in high-precision measurements based on atom interferometry. However, in order to reach such long evolution times, it is necessary to employ ultracold atoms combined with matter-wave lensing techniques, and a detailed modeling is required. Here we present the results of 3D numerical simulations of BECs freely expanding for tens of seconds. As an application, we investigate the long-time behaviour of a BEC whose expansion has been collimated through matter-wave lensing. In particular, we examine the role played by the repulsive mean-field interaction and by quantum effects due to Heisenberg's uncertainty principle and the finite size of the BEC. Their relative importance is compared under different conditions.

Q 22.71 Tue 16:30 Empore Lichthof

High-order harmonic generation in gases with μJ laser pulses — •Matthias Meier[1], Philip Dienstbier[1], Yuya Morimoto[2], Francesco Tani[3], and Peter Hommelhoff[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]RIKEN Cluster for Pioneering Research (CPR), RIKEN Center for Advanced Photonics (RAP), Japan — [3]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

Pump-probe schemes involving strong few-cycle driving pulses in the infrared in combination with attosecond probe pulses in the extreme ultraviolet are a powerful spectroscopic tool to investigate the ultrafast dynamics of electrons inside materials. For many spectroscopic schemes, it is desirable or even necessary to provide pump and probe pulses at high repetition rates for sufficient statistics and signal-to-noise ratios in the detection. Here, we present a laser system delivering infrared near infrared 8 fs pulses with 18 μJ energy and repetition rates up to 1 MHz. The few-cycle pulses are obtained by shortening 210 fs pulses from an Ytterbium laser amplifier with stable carrier-envelope phase. For this we use a two-stage compressor based on two argon-filled hollow-core photonic crystal fibers. The pulses are then delivered to a vacuum chamber which is set up for generating and characterizing isolated attosecond pulses.

Q 22.72 Tue 16:30 Empore Lichthof

The Parity Interferometer — •Freyja Ullinger[1,2] and Matthias Zimmermann[1] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany — [2]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89081 Ulm, Germany

The quantum-mechanical parity operator enables the reconstruction of the phase space representation of a quantum state [1,2,3,4]. However, the implementation of the parity operation is a subtle issue.

In this poster, we reveal the intrinsic relation between the parity operator and the quantum-mechanical harmonic oscillator. In particular, we present two methods for its realization: (i) we rely on a continuous time evolution in a harmonic potential, and (ii) we employ a combination of pulsed harmonic potentials and free propagation.

By exploiting these methods, we construct a novel parity interferometer. The output of our device measures the parity of a given initial state.

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[2] S. Haroche, M. Brune, and J. M. Raimond, J. Mod. Opt. **54**, 2101 (2007)
[3] R. J. Birrittella, P. M. Alsing and C. C. Gerry, AVS Quantum Sci. **3**, 014701 (2021)
[4] S. Kleinert, 'Relativity, States and Quantum Evolutions in Atom Interferometry', Ph.D. thesis (Ulm University, Ulm, 2018)

Q 22.73 Tue 16:30 Empore Lichthof

Dynamics of quantum gases mixtures in space experiments — •Annie Pichery[1,2], Matthias Meister[3], Eric Charron[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, France — [3]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany

Ultra-cold atomic ensembles are a prime choice for sources in quantum sensing experiments. Space provides an environment where these clouds can float for extended times of several seconds, thus boosting the precision of these sensors. It also enables the operation of Bose-Einstein Condensate (BEC) mixtures for dual interferometers in miscibility conditions not possible on ground.

Simulating such dynamics of interacting dual species BEC mixtures presents however computational challenges due to the long expansion times. In this contribution, scaling techniques to overcome these limits are presented and illustrated in the case of space experiments on the ISS and aboard sounding rockets.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. CAL-II 50WM2245A/B.

Q 22.74 Tue 16:30 Empore Lichthof

Deep Learning Accelerated FDFD Simulations in Context of Inverse-Design Algorithms — •Lukas Schulte, Marco Butz, and Carsten Schuck — Center for Soft Nanoscience, Münster, Germany

Deep learning (DL) methods have shown tremendous success in various disciplines related to the design of photonic integrated circuit components. Likewise various fields of simulation, such as fluid dynamics, DL might be used to accelerate electromagnetic first-order simulations, as well.

To numerically access the photonic properties of metamaterials, efficient electromagnetic simulation algorithms are obligatory. In order to simulate the propagation of light through nanophotonic devices, various numerical methods, such as the finite-difference frequency-domain method (FDFD), have been developed. Requiring to solve large sparse linear systems iteratively, these methods come at the cost of being computationally expensive processes.

Here, we show how DL can be employed to decrease the computational effort of consecutive FDFD simulations, for example, encountered in inverse-design algorithms. Leveraged by the U-Net architecture our method is capable of predicting the electromagnetic response of a nanophotonic device. We use this prediction as a starting point for iterative refinement using FDFD, thus decreasing the required iteration and computation time drastically. Hereby, we minimize the overall time required by inverse-design algorithms to reach convergence and thus enable more sophisticated device layouts.

Q 22.75 Tue 16:30 Empore Lichthof

Stability of bound states in the continuum in one-dimensional resonator — •Ekaterina Maslova, Mikhail Rybin, Andrey Bogdanov, and Zarina Sadrieva — Saint-Petersburg, Russia

Bound states in the continuum (BIC) are resonances with infinite radiative quality (Q) factor. Although infinite Q factor is a mathematical abstraction, high-Q supercavity modes whose origin corresponds to genuine BIC can be excited in real samples. We consider Q-factor of BIC in one-dimensional resonators consisting of dielectric blocks. We investigate the dependence of the Q-factor on the structural disorder in symmetric and asymmetric structures. Symmetric structure unit cell consists of two similar blocks, while in asymmetric case there are two types of blocks with different size parameters. We studied electromagnetic waves in a finite array of blocks, which were calculated using the numerical simulation by finite difference method. The results show that in an asymmetric system the Q-factor is resistant to the introduction of structural disorder.

Q 22.76 Tue 16:30 Empore Lichthof

Deep Learning Accelerated FDFD Simulations in Context of Inverse-Design Algorithms — •Lukas Schulte[1,2,3], Marco Butz[1,2,3], and Carsten Schuck[1,2,3] — [1]Center for Soft Nanoscience, Münster, Germany — [2]Center for Nanotechnology, Münster, Germany — [3]Institute of Physics, University of Münster

Deep learning (DL) methods have shown tremendous success in various disciplines related to the design of photonic integrated circuit components. Similarly, DL may be used to accelerate electromagnetic first-order simulations. To numerically access the photonic properties of metamaterials requires efficient electromagnetic simulation algorithms. In order to simulate the propagation of light through nanophotonic devices, various numerical methods, such as the finite-difference frequency-domain method (FDFD), have been developed. Requiring to solve large sparse linear systems iteratively, these methods come at the cost of being computationally expensive processes. Here, we show how DL can be employed to decrease the computational effort of consecutive FDFD simulations, for example, encountered in inverse-design algorithms. Leveraging the U-Net architecture our method is capable of predicting the electromagnetic response of a nanophotonic device. We use this prediction as a starting point for iterative refinement using FDFD simulation, thus decreasing the required iteration and computation time drastically. Hereby, we minimize the overall time required by inverse-design algorithms to reach convergence and thus enable more efficient and compact device layouts.

Q 22.77 Tue 16:30 Empore Lichthof

Inverse design of dielectric laser accelerators and Smith-Purcell radiators — •Manuel Konrad, Michael Seidling, Urs Haeusler, Roy Shiloh, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Computational design and especially the inverse design approach are powerful tools for the design of nanophotonic structures. In inverse design, the structure is optimized according to an objective function, using an arbitrarily large number of parameters. The great advantage of inverse design over other schemes lies in the independence of the computational effort from the number of parameters, meaning one can efficiently explore a large parameter space. This often results in complex structures, which differ drastically from designs based on human intuition. With this design tool, various applications have already been demonstrated, such as highly efficient waveguides, complex optical demultiplexers, and different kinds of optical circuitry [1], but also for quantum correlations [2] and highly efficient light coupling to photonic nanostructures, used in dielectric laser acceleration of electrons [3]. We apply inverse design to the dielectric laser acceleration of electrons and Smith-Purcell radiation [4], while staying within the well-tested confines of silicon photonics. Our aim is to improve the performance of the current generation of structures with this novel technique.

[1] Molesky et al. Nature Photon 12, 659 (2018) [2] Dahan et al. Science 373, eabj7128 (2021) [3] Sapra et al. Science 367, 79 (2020) [4] Haeusler et al. ACS Photonics, 9, 2, 664 (2022)

Q 22.78 Tue 16:30 Empore Lichthof

Suppression of soliton-fission by a Zeno-like effect — •Niklas Bahr, Stephanie Willms, Ihar Babushkin, Uwe Morgner, Oliver Melchert, and Ayhan Demircan — Leibniz University Hannover, Cluster of Excellence PhoenixD, Hannover, Germany

The quantum mechanical Zeno-effect states that the spontaneous decay of an unstable quantum system can be inhibited by continuous measurements. We consider pulse propagation in nonlinear waveguides in terms of a generalized nonlinear Schrödinger equation, wherein linear loss assumes the role of continuous measurements within the quantum context. Under presence of perturbations, e.g. third order dispersion, a higher order soliton tends to decay in fundamental solitons. The reason for this is a process called soliton fission where, due to the spectral expansion of the soliton, energy is transferred to a phase matched resonant frequency. In this work, we show that upon tailoring the absorption characteristics so that the resonant frequency experiences loss, the breakup of higher-order solitons can be slowed down or even suppressed. We further show that this approach also applies to modulation instability induced soliton fission.

Q 22.79 Tue 16:30 Empore Lichthof

Bandwidth Optimization of SNSPDs Cryogenic Readout for Low-Jitter — •Roland Jaha[1,2], Wolfram Pernice[3], and Simone Ferrari[3] — [1]Institute of Physics, Münster 48149, Germany — [2]Center for Soft Nanoscience, Münster 48149, Germany — [3]Kirchhoff-Institute of Physics, Heidelberg 69120, Germany

High temporal resolution is a crucial performance metric of superconducting nanowire single-photon detectors (SNSPDs), as it would allow for increased rates in quantum key distribution (QKD) and optical sampling scopes with superior bandwidth. In recent years, considerable effort was made to improve the timing precision and sub-5 ps jitter has been demonstrated in the near-infrared. However, achieving this high temporal resolution goes in most cases at the cost of other performance metrics, such as detection efficiency. Therefore, while the community has been mainly invested in improving the detector geometry or material composition, we shift our focus towards the optimization of the electrical readout. We believe that in this way we can obtain low jitter while leaving other specifications relatively untouched. For our experiments, we design and fabricate cryogenic low-noise amplifiers (C-LNAs) with different readout bandwidths. The cryogenic operation allows for a significant reduction of the voltage noise, which is one of the main contributors to the timing jitter. Moreover, by tuning the amplifier bandwidth we are able to further improve the temporal resolution of the detector. We demonstrate that enhancing the low-frequency cutoff of the amplifier from 1 MHz to 200 MHz it is possible to reduce the timing jitter by more than 15 ps.

Q 22.80 Tue 16:30 Empore Lichthof

Integrated optical waveguides for the near-ultraviolet to blue visible spectral range for chip-based trapped-ion quantum computers — •Pascal Gehrmann[1,2], Anastasiia Sorokina[1,2], Carl-Frederik Grimpe[3], Guochun Du[3], Tunahan Gök[6,7], Radhakant Singh[6,7], Pragya Sah[6,7], Babita Negi[7], Maxim Lipkin[6,7], Stephan Suckow[6], Elena Jordan[3], Steffen Sauer[1,2], Tanja Mehlstäubler[3,4,5], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nano- und Quantenengineering, Hannover, Germany — [6]AMO GmbH, Advanced Microelectronic Center Aachen, Aachen, Germany — [7]Chair of Electronic Devices, RWTH Aachen University, Aachen, Germany

Photonic integrated circuits (PICs) for on-chip light manipulation can be employed in scalable chip-based trapped-ion quantum computers. Trapped ions are used as qubits and are controlled by multiple wavelengths ranging from the near-ultraviolet (NUV) up to the near-infrared (NIR). The design of UV-PICs is a challenging task, since smaller dimensions and higher propagation losses are inevitable. This contribution covers the design of single-mode integrated optical waveguides on different material platforms for selected NUV and VIS wavelengths of an Yb^+ ion. To improve the scalability, multi-wavelength operation is investigated.

Q 22.81 Tue 16:30 Empore Lichthof

Anisotropic properties of light-propelled microswimmers — •Elena Vinnemeier[1], Matthias Rüschenbaum[1], Cornelia Denz[1,2], and Jörg Imbrock[1] — [1]Institut für Angewandte Physik, Münster, Deutschland — [2]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Deutschland

Self-propelled particles enable versatile applications in various fields like in colloidal systems or in biomedicine. Utilizing light as an energy source is advantageous, since a fuel-free and highly controllable motion is possible. We demonstrate a novel propulsion mechanism relying solely on refraction of light, while an asymmetric particle shape and a symmetry-broken refractive index profile lead to a directional propulsion force. For fabrication of microswimmers direct laser writing by two-photon polymerization is employed. We compare the performance of these light-propelled particles with respect to velocity and directionality for different geometries and refractive index gradients.

Q 22.82 Tue 16:30 Empore Lichthof

Photonic integrated receiver concept for quantum communication — •Marco Dietrich[1,2], Bastian Hacker[1], Jonas Pudelko[1,2], Ömer Bayraktar[1,2], Francesco Morichetti[3], and Christoph Marquardt[1,2] — [1]Max Planck Institut für die Physik des Lichts, Staudstr. 2, 91058 Erlangen — [2]Institut für Optik, In-

formation und Photonik, FAU Erlangen-Nürnberg, Staudstr. 7, 91058 Erlangen — [3]Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Milan, Italy

Quantum Key Distribution (QKD) in free space requires the efficient reception of distorted optical modes. We investigate an interferometer mesh on a Photonic Integrated Chip (PIC) with the goal to correct the individual optical phases of several spatial input regions and coherently combine an arbitrary incident wavefront into a single fiber mode. Active elements allow for dynamical adaption to a changing input mode. This approach provides good passive stability and offers high scalability. We study this concept in the context of quantum communication with a realistic cubesat payload.

Q 22.83 Tue 16:30 Empore Lichthof

Ultra-low-loss non-reciprocal devices based on acousto-optic interaction in fiber null-couplers — •Riccardo Pennetta, Martin Blaha, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt Universität zu Berlin, 12489 Berlin, Germany

The introduction of low-loss optical fibers probably represents the single most important advance in the growth of our telecommunication system. To meet our needs for secure communications, it is likely that our classical network will soon be operating alongside what is known as a quantum network. The latter is very sensitive to loss and thus poses new constraints to the performance of current fiber components. In particular, recent quantum network prototypes underlined the surprising absence of low-loss non-reciprocal fiber-based devices. Here, we present a solution to this issue by the proof-of-principle demonstration of ultra-low-loss (<0.1 dB) non-reciprocal devices (both isolators and circulators) based on so-called fiber null-couplers. The splitting ratio of these couplers can be controlled via acousto-optic interaction of the propagating light field with flexural acoustic waves that one launches along the coupling region. Fabricated from standard single-mode fibers, these devices are compatible with existing optical networks and could represent one important ingredient for the transmission and processing of optically encoded quantum information.

Q 22.84 Tue 16:30 Empore Lichthof

Fabrication of Computer-Generated Nanophotonic Devices — •David Lemli, Marco Butz, and Carsten Schuck — Institute of Physics, University of Münster, Germany

The increasingly sophisticated functionalities and performance requirements of photonic integrated circuit components produced by modern inverse design algorithms are practically difficult to achieve due to limitations of state-of-the-art nanofabrication processes. The main challenge consists in producing irregular computer-generated structures with 10s of nanometer resolution and high aspect ratios. In this work, we address this challenge with a holistic approach that combines electron-beam lithography and focused-ion-beam milling techniques with biasing deep-learning-based design algorithms to account for arbitrary fabrication constraints while minimizing the impact on individual device performance. We employ our methods for fabricating a wide range of pixel-discrete inversely designed nanophotonic structures and compare the measured performances with simulation based predictions. Our findings pave the way for fast and exact prototyping of novel and challenging nanophotonic devices for applications in information and communication technology, including photonic quantum technology.

Q 22.85 Tue 16:30 Empore Lichthof

Optical reservoir computing with incoherent optical memory — •Mingwei Yang[1,2], Elizabeth Robertson[1,2], Leon Messner[1,3], Norman Vincenz Ewald[1], Luisa Esguerra[1,2], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt, Institute of Optical Sensor Systems, Rutherfordstraße 2, Berlin, Germany. — [2]Technische Universität Berlin, Berlin, Germany. — [3]Humboldt-Universität zu Berlin, Berlin, Germany.

Reservoir computing is a machine learning method that is particularly suited for dynamic data processing. A fixed reservoir projects the input information to a high-dimensional feature space, and only the readout weights need to be trained, allowing fast data processing with low energy consumption [1]. In this work, we demonstrate an optical reservoir computing using incoherent memory in a cesium vapor cell to predict time-series data. The information is stored in the reservoir by controlling the pump and probe process on the Cs D2 transitions. The coupling between the reservoir and both the input and output data is realized by acousto-optic modulators. [1] G. Tanaka, T. Yamane, J. B. Héroux, R. Nakane, N. Kanazawa, S. Takeda, H. Numata, D. Nakano, and A. Hirose, *Recent advances in physical reservoir computing: A review,* Neural Networks 115, 100*123 (2019). [2] L. Jaurigue, E. Robertson, J. Wolters, and K. Lüdge, *Photonic reservoir computing with non-linear memory cells: interplay between topology, delay and delayed input,* in Emerging Topics in Artificial Intelligence (ETAI) 2022, vol. 12204 (SPIE, 2022), pp. 61*67.

Q 22.86 Tue 16:30 Empore Lichthof

Structuring hydrogels by two-photon lithography inside microfluidic channels for cell migration experiments — •Elena Bekker[1], Dustin Dzikonski[1], Riccardo Zamboni[1], Jörg Imbrock[1], and Cornelia Denz[1,2] — [1]Insitute of Applied Physics, University of Münster, Corrensstraße 2-4, 48149 Münster, Germany — [2]Physikalisch-Technische Bundesanstalt, Budesallee 100, 38116 Braunschweig, Germany

Hydrogels are highly swellable polymers which generally possess excellent biocompatibility and tissue-like properties. They can be structured via direct laser writing by two-photon lithography (2PL), enabling the fabrication of three-dimensional arbitrary structures with high resolution and spatial complexity. Using this technique, the microenvironment of cells can be mimicked with a high degree of control and reproducibility, whilst allowing variation in the physical properties of the structured gels. We perform 2PL fabrication inside channel systems of microfluidic devices, which provide a three-dimensional culture chamber for cells and allow the generation of chemical gradients to stimulate directed migration towards chemoattractant species. In this way, we investigate cell migration in confined three-dimensional environments.

Q 23: Optomechanics I & Optovibronics

Time: Wednesday 11:00–12:45 Location: A320

Q 23.1 Wed 11:00 A320

Quantum optomechanics with a levitated nanoparticle and an on-chip photonic crystal cavity — •Seyed Khalil Alavi[1,2], Jin Chang[3], Danial Davoudi[1], Marion Hagel[4], Simon Gröblacher[3], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universität Stuttgart, Stuttgart, DE — [2]Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, DE — [3]Kavli Institute of Nanoscience, Department of Quantum Nanoscience, Delft University of Technology, Delft, The Netherlands — [4]Max Planck Institute for Solid State Research, Stuttgart, DE

A levitated dielectric nanoparticle coupled to an optical cavity is a promising platform for quantum optomechanics. Recent progress includes cooling the particle's motion to the ground state achieved with a conventional optical cavity. A photonic crystal nanocavity (PCN) is an attractive alternative offering enhanced optomechanical coupling. The optomechanical coupling up to 10 kHz has been previously demonstrated with a stand-alone PCN. However, the system's fragility to optical absorption and mechanical perturbation prevented further advancement toward the quantum regime. In this talk, we present a new platform based on an on-chip PCN that can achieve the goal. The new PCN architecture ensures significantly improved mechanical and thermo-optic stability, allowing experiments at a high vacuum and with a large number of intracavity photons. We discuss our recent progress toward obtaining the quantum cooperativity above one.

Q 23.2 Wed 11:15 A320

Optoacoustic active phonon cooling in waveguides — •Laura Blázquez Martínez[1], Philipp Wiedemann[1], Andreas Geilen[1], Changlong Zhu[1], and Birgit Stiller[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058, Erlangen, Germany — [2]Physics department office, FAU Erlangen-Nürnberg, Staudtstr. 7 / B2, 91058, Erlangen, Germany

Optomechanical cooling is usually observed in resonator-based setups. In waveguides, active cooling via optomechanical or optoacoustic interactions is still largely unexplored. Here, we demonstrate experimentally active optoacoustic phonon cooling using the nonlinear effect of Brillouin-Mandelstam scattering in a chalcogenide glass photonic crystal fibre (PCF). The regime of height saturation for the anti-Stokes peak is demonstrated experimentally. Based on the Brillouin resonance behaviour, we show cooling by a temperature difference of $\Delta T \approx 190$ K from room temperature at 7.53 GHz, exceeding 3 times previously reported values.

Q 23.3 Wed 11:30 A320

Coherent control of Brillouin optomechanics in waveguides — •Changlong Zhu[1], Junyin Zhang[1], Christian Wolff[2], and Lijun Qiu[1] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Centre for Nano Optics, University of Southern Denmark, Campusvej 55, DK-5230, Odense M, Denmark

Brillouin optomechanics in waveguides allows a triply-resonant interaction between an optical, scattered light, and an acoustic wave. Here, we present a formalism to describe backward Brillouin optomechanics in waveguides in the dynamic regime with a pulsed pump. This formalism reveals the connection between waveguide Brillouin optomechanics and cavity optomechanics. By utilizing this theoretical framework, we show a closed solution for the coupled-mode equation of Brillouin optomechanics under the undepleted assumption, which can be used to investigate the coherent control of waveguide optomechanics in the quantum regime, such as coherent photon-phonon transfer, phonon cooling, and photon-phonon entanglement. In addition, we propose a dynamic Brillouin cooling scheme in Brillouin-active integrated waveguides, where the optical dissipation exceeds the mechanical dissipation which is the common case in optical waveguides. By modulating the coupling intensity of the backward Brillouin anti-Stokes interaction via a pulsed pump, a phonon cooling factor with several orders of magnitude can be achieved.

Q 23.4 Wed 11:45 A320

Quantum optics approach to non-adiabatic phenomena in molecules — •Michael Reitz[1], Jacopo Fregoni[2], Raphael Holzinger[3], Agnes Vibok[4], and Claudiu Genes[1,5] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, Madrid, Spain — [3]Institut für Theoretische Physik, University of Innsbruck, Innsbruck, Austria — [4]Department of Theoretical Physics, University of Debrecen, Debrecen, Hungary — [5]Physics Department, Friedrich-Alexander Universität Erlangen-Nürnberg, Erlangen, Germany

We propose an open quantum system approach to non-adiabatic phenomena in molecules, especially relevant during or after photoexcitation. In particular, we provide analytical approaches that qualitatively describe processes such as nonradiative transitions, internal conversion and intersystem crossing. The main overarching aspect of this theory is the derived unidirectionality of transfer between higher energy electronic states to lower energy states mediated by nonadiabatic couplings followed by quick vibrational relaxation, i.e., the often invoked Kasha's rule.

Q 23.5 Wed 12:00 A320

Nonlinear opto-vibronics in molecular systems — Quansheng Zhang[1], •Micheal Reitz[1], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, Erlangen, Germany

Opto-vibrational interactions in molecular systems occur in a hybrid fashion as light couples to electronic transitions, which in turn are modified by the vibrations of the nuclei. In standard approaches, under the Born-Oppenheimer approximation, the vibronic coupling is a spin-boson interaction modeled by a Holstein Hamiltonian, i.e., an electronic transition between two copies of the same harmonic potential landscape is slightly shifted. However, the potential landscapes for the excited and ground electric states may be different, with two different frequencies for the two harmonic curves. In such a case, the polaron transformation is modified by an operation involving a conditional squeezing operator.

We present here an analytical treatment based on a set of quantum Langevin equations for elective spin operators dressed by oscillations. These equations can be solved under some approximations to obtain information on emission and absorption spectra. Moreover, we propose to exploit the intrinsic nonlinear vibronic interaction to map light states to nuclear vibrations and viceversa. Our results are also applicable to quadratic optomechanics, such as in the membrane-in-the-middle scenario.

Q 23.6 Wed 12:15 A320

Interaction-Induced Directional Transport on Driven Coupled Chains — •Helena Drüeke and Dieter Bauer — Universität Rostock

We examine whether interaction between particles may introduce (topologically protected) directional transport in a driven two-particle quantum system. As a simple example, we consider two one-dimensional chains of equal length, each with one particle. The two particles interact but stay on their respective chain. The particles move alternatingly and without a preferred direction.

Without interaction between the particles, they each diffuse along their chains. Interaction between them suppresses this diffusion. With the proper timing of their alternating movement, the particles form a bound doublon state. Depending on their starting positions, this doublon either remains stationary or moves along the chain. The motion of the doublon consists of alternating, leapfrogging motion of the two particles.

Q 23.7 Wed 12:30 A320

Teaching Quantum Optics and Quantum Cryptography with Augmented Reality Enhanced Experiments — •Adrian Abazi[1], Paul Schlummer[2], Jonas Lauströer[3], Jochen Stuhrmann[3], Rasmus Borkamp[3], Wolfram Pernice[1], Reinhard Schulz-Schaeffer[3], Stefan Heusler[2], Daniel Laumann[2], and Carsten Schuck[1] — [1]Center for Nanotechnology, WWU Münster — [2]Institut für Didaktik der Physik, WWU Münster — [3]Department Design, HAW Hamburg

Recently, the Nobel Prize in physics was awarded for experiments with entangled photons, pioneering quantum technologies. To meet the growing demand of this field by furthering scientific comprehension of quantum physics and quenching misconception, especially about entanglement, new teaching approaches are required. Addressing this, we present a mixed reality quantum learning environment, by integrating commercially available AR-Headsets with a quantum optics setup for photon-pair generation and bell measurements. Students measure Bells inequality and conduct a version of the Ekert 91 quantum key distribution protocol. Simultaneously, visualizations of the underlying models and measurement results are rendered as holograms on appropriate locations of the optics setup. Dedicated actions, such as choosing a measurement basis, are reflected in the visualizations in real time. The learning environment has been implemented and is tested in undergraduate lab-courses. The components and software of the environment have been chosen to ease modifications and transfer.

Q 24: Quantum Networks I (joint session QI/Q)

Time: Wednesday 11:00–12:45 Location: B305

Invited Talk Q 24.1 Wed 11:00 B305

Self-testing with dishonest parties and entanglement certification in quantum networks — •Gláucia Murta[1] and Flavio Baccari[2] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, Garching 85748, Germany

Multipartite entanglement is a crucial resource for network cryptographic tasks, such as secret sharing and anonymous quantum communication. Here, we consider the task of entanglement verification in a quantum network. The goal is to certify entanglement of the distributed state even when some of the parties (an unknown subset of parties in the network) may act maliciously. Our main result is a device-independent verification protocol that can certify genuine multipartite entanglement in the presence of dishonest parties. Our protocol is based on the Svetlichny inequality, and we show that the maximal violation of the Svetlichny inequality can self-test the GHZ state even in the presence of dishonest parties.

Q 24.2 Wed 11:30 B305

Extracting maximal entanglement from linear cluster states — •Jarn de Jong[1], Frederik Hahn[1], Nikolay Tcholtchev[2], Manfred Hauswirth[2], and Anna Pappa[1,2] — [1]Electrical Engineering and Computer Science Department, Technische Universitaet Berlin, 10587 Berlin, Germany — [2]Fraunhofer Institute for Open Communication Systems - FOKUS, 10589 Berlin, Germany

Most quantum information processing architectures only allow for nearest-neighbour entanglement creation. In many cases, this prevents the direct generation of maximally entangled states, which are commonly used for many communication and computation tasks. Here we show how to obtain maximally entangled GHZ states between vertices initially connected by a minimum number of connections, which specifically allows them to share linear cluster states. We prove that the largest GHZ state that a linear cluster state on n qubits can be transformed into by means of local Clifford unitaries, local Pauli measurements and classical corrections, is of size $\lfloor (n+3)/2 \rfloor$. We demonstrate exactly which qubit selection patterns are possible below this threshold and which are not, and implement the transformation on the `IBMQ Montreal` quantum device for linear cluster states of up to $n = 19$ qubits.

Q 24.3 Wed 11:45 B305

Aging effects in multiplexed quantum networks — •Lisa T. Weinbrenner[1], Lina Vandré[1], Tim Coopmans[2], and Otfried Gühne[1] — [1]Universität Siegen, Germany — [2]Universiteit Leiden, Netherlands

Aging is a well known problem which effects humans as well as technical devices. It is described by the effect that the probability for a failure in a given time interval increases with the life time of the biological or technological object. Different types of objects (e.g. humans and technical devices) age according to qualitatively different failure rates. The difference can be understood if these objects are modeled as systems of redundant parts with possibly initial defects [1].

Multiplexed quantum networks are quantum networks with multiple connections between two nodes, i.e., with redundancy in the edges of the network [2]. The functionality of the entire network depends on the functionality of the technical devices used. This leads to the question how the failure rates of the single devices lead to aging effects in the entire network. In this contribution we will apply the theory of aging to the technical devices used in a multiplexed quantum network. Our results rely on the analytical treatment of the underlying stochastic process of failure of the devices, as well as numerical simulations for different network structures.

[1] L. A. Gavrilov and N. S. Gavrilova, J. Theor. Biol. 213, 527-545 (2001)

[2] O. A. Collins et al., Phys. Rev. Lett 98, 060502 (2007)

Q 24.4 Wed 12:00 B305

Cavity-Assisted Entanglement Generation between Spins and Photon Pulses — •Ferdinand Omlor, Benedikt Tissot, and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

The reliable entanglement generation between distant nodes of a quantum network is a core challenge for the realization of quantum communication. Spin qubits contained in optical cavities are promising systems which can be interconnected by photons using fiber optics. So far the focus of theoretical studies was on single modes. We present a way to study multimode signals, in particular pulses of finite duration. This multimode character needs to be taken into account to correctly calculate the fidelity of entanglement generation between a single photon pulse and a spin qubit. We specifically study this with the network architecture proposed by K. Nemoto et al., Phys. Rev. X 4, 031022 (2014) in mind.

Q 24.5 Wed 12:15 B305

A Graphical Formalism for Entanglement Purification — •Lina Vandré and Otfried Gühne — Universität Siegen, Germany

Hypergraph states form an interesting family of multi-qubit quantum states which are useful for quantum error correction, non-locality and measurement-based quantum computing. They are a generalisation of graph and cluster states. The states can be represented by hypergraphs, where the vertices and hyperedges represent qubits and entangling gates, respectively.

For quantum information processing, one needs high-fidelity entangled states, but in practice most states are noisy. Purification protocols address this problem and provide a method to transform a certain number of copies of a noisy state into single high-fidelity state. There exists a purification protocol for hypergraph states [1]. In my talk, I will first reformulate the purification protocol in a graphical manner, which makes it intuitively understandable. Based on this, I will propose systematic extensions, which naturally arise from the graphical formalism.

[1] T. Carle et al., Phys. Rev. A 87, 012328 (2013)

Q 24.6 Wed 12:30 B305

Generation of multidimensional entanglement in quantum optical systems — •Felix Twisden-Peareth, Jan Sperling, and Polina Sharapova — Paderborn University, Warburger Str. 100 | 33098 Paderborn

Multidimensional entanglement is a key source for many quantum applications, such as quantum computing, quantum communication and quantum simulation [1].
In this work, we investigate a four-channeled quantum optical system, which is driven by two spontaneous parametric down-conversion (SPDC) sources (each emitting two photons), in order to find configurations that generate maximal entanglement. The entanglement is quantified by the Schmidt number $\mathrm{K} = \mathrm{Tr}[\rho_r^2]^{-1}$, which is applicable to both pure and mixed states [2]. In our system, to calculate the Schmidt number, we provide reductions regarding both frequencies and spatial channels. In order to affect the entanglement, the photons in the system are manipulated regarding their polarization and relative position by introducing a time delay. It was found that Schmidt numbers equal to the dimensionality of the system can be generated. For this, the generation of a coherent superposition of different polarizations is provided, which is followed by a temporal separation of its parts. All results are calculated for the material system $LiNbO_3$.

[1] J. Wang, et al., Multidimensional quantum entanglementwith large-scale integrated optics, Science **360**, 285*291 (2018).
[2] B. M. Terhal and P. Horodecki, Schmidt number for density matrices, Physical Review A **61**, 040301 (2000).

Q 25: Solid State Quantum Optics

Time: Wednesday 11:00–13:00 Location: E001

Q 25.1 Wed 11:00 E001

Temperature annealing of hBN single-photon emitters in a nitrogen-rich atmosphere — •Nora Bahrami[1,2], Pablo Tieben[1,2], Janosch Stutenbaeumer[1], and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Gottfried Wilhelm Leibniz Universität, Hannover, Germany

Single-photon emitters (SPEs) are becoming increasingly important due to their diverse use in quantum photonics, such as quantum communication and metrology. Especially hexagonal boron nitride (hBN), a two-dimensional semiconductor material, has recently gained interest because of its remarkable optical properties, such as bright emission at room temperature across the visible and near infrared spectral range owing to the large bandgap of 6 eV. Nevertheless the nature of this emission, i.e., its atomic origin, is still undefined and fluorescence bleaching is an unfortunate occurrence for integrated applications, where stable emission is significant for further research. Therefore we evaluate a recipe to enhance the spectral characteristics in hBN flakes by high temperature annealing in a nitrogen-rich atmosphere. Individual emitters were characterized and compared on certain areas via photoluminescence mapping and by the analysis of g(2) -, saturation-and lifetime measurements as well as emission spectra before and after annealing. Our research opens up another step towards improving the optical properties of hBN.

Q 25.2 Wed 11:15 E001

Enhanced photon emission from hBN defects centers inside a tunable fiber-cavity — •Gregor Bayer[1], Florian Feuchtmayr[1], Stefan Häussler[1,2], Richard Waltrich[1], Noah Mendelson[3], Chi Li[3], David Hunger[4], Igor Aharonovich[3,5], and Alexander Kubanek[1,2] — [1]Inst. f. Quantenoptik, Uni Ulm, D — [2]Center f. Integ. Q. Science and Techn. (IQst), D — [3]School of Math./ Phys. Sciences, Univ. of Tech. Sydney, AUS — [4]Phys. Institut, Karlsruhe Inst. of Tech., D — [5]ARC Centre of Exc. f. Transf. Meta-Optical Systems, Univ. of Tech. Sydney, AUS

Coupling single quantum emitters to the mode of optical resonators is essential for the realization of quantum photonic devices. We present a hybrid system consisting of defect centers in a few-layer hexagonal boron nitride (hBN) sheet and a fiber-based Fabry-Pérot cavity. The smooth surface of the chemical vapor deposition grown hBN layers enables efficient integration into the cavity. This hybrid platform is operated over a broad spectral range of more than 30 nm. Owing to cavity funneling, large cavity-assisted signal enhancement up to 50-fold and strongly narrowed linewidths are demonstrated, a record for hBN-cavity systems. On top, we implement an excitation and readout scheme for resonant excitation, allowing to establish cavity-assisted photoluminescence excitation spectroscopy. In total, we reach a milestone for the deployment of 2D materials to fiber-based cavities in practical quantum technologies.

Q 25.3 Wed 11:30 E001

Mechanically Isolated Quantum Emitters in Hexagonal Boron Nitride. — •Patrick Maier[1], Andreas Tangemann[1], Michael Koch[1], Michael Höse[1], Igor Aharonovich[2], T.T. Tran[2], Niklas Lettner[1], Lukas Antoniuk[1], and Alexander Kubanek[1] — [1]University of Ulm, Germany — [2]University of Technology Sydney

Single Photon emitters are a crucial resource for novel photonic quantum technologies. Quantum emitters hosted in two-dimensional hexagonal Boron Nitride (hBN) are a promising candidate for the integration into hybrid quantum systems. One type of emitters hosted in hBN has shown the remarkable property of Fourier limited linewidths from cryogenic up to room temperatures. This property can be attributed to mechanically isolated orbitals of the defect centers, which do not couple to in-plane phonon modes. Here, we present our recent results towards identifying the origin of this mechanical decoupling, which could be caused by out-of-plane emitters. We also present quantum random number generations using the symmetric dipole emission profile of these emitters.

Q 25.4 Wed 11:45 E001

Super-Poissonian Light Statistics from Individual Silicon Vacancy Centers Coupled to a Laser-Written Diamond Waveguide — •Michael K. Koch[1,2], Michael Hoese[1], Vibhav Bharadwaj[1,3], Johannes Lang[1], John P. Hadden[4], Roberta Ramponi[3], Fedor Jelezko[1,2], Shane M. Eaton[3], and Alexander Kubanek[1,2] — [1]Ulm University, D-89081 Ulm, Germany — [2]IQst, Ulm University, D-89081 Ulm, Germany — [3]Institute for Photonics and Nanotechnologies (IFN) - CNR, Milano 20133, Italy — [4]School of Physics and Astronomy, Cardiff University, Cardiff CF24 3AA, United Kingdom

Light field engineering on the single photon level is a key challenge for future quantum technology. Ideally, it will be realized with integrated quantum photonics to ensure robustness and scalability. Here we present a system that combines single silicon vacancy centers (SiVs) with laser-written type II waveguides [1] in diamond. Typically, these waveguides exhibit low cooperativity at the single photon level due to their large mode volume. To overcome this limitation, we use a novel operational technique of waveguide-assisted detection and high numerical aperture excitation of SiV centers to achieve a strong non-linearity at the single photon level. We demonstrate single-emitter extinction measurements with a cooperativity of 0.0050 and a relative beta factor of 13% [2].

[1] M. Hoese et al., Phys. Rev. Applied 15, 054059 (2021)
[2] M. K. Koch et al., ACS Photonics 9, 3366-3373 (2022)

Q 25.5 Wed 12:00 E001

Cavity-enhanced extinction measurements of nanoscale structures — •Ines Amersdorffer[2,1], Florian Sigger[3], Thomas Hümmer[2,1], Jonathan Noé[2,1], Alexander Högele[1], Christoph Kastl[3], and David Hunger[4] — [1]Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany — [2]Qlibri GmbH, Munich, Germany — [3]Walter Schottky Institute and Physics Department, Technical University of Munich, Germany — [4]Physikalisches Institut, Karlsruhe Institute of Technology, Germany

Measurements of the marginal absorption of nanomaterials are challenging. One way to address this issue is the use of an optical resonator in which the light passes the sample multiple times and thereby enhances the absorption of nanoscale objects to a measurable amount. We demonstrate how a high-finesse microcavity can be utilised in order to measure the extinction of defects in monolayer MoS_2. Such atomistic defects embedded in nanomaterials are a promising candidate for single-photon sources. However, to make them optically accessible, it is beneficial to know their absorption properties. To this end, we performed wavelength-dependent extinction measurements. The absolute values of extinction were recorded with a detection limit of down to 0.01 % and agree with theoretical predictions. Furthermore, we show first insights from applying this novel microscopy technique to perovskite nanocubes. Spectroscopy on single perovskite crystals helps to pick and engineer them for suitable applications, e.g. LEDs. The results show advances towards routine hyperspectral absorption measurements on the nanoscale.

Q 25.6 Wed 12:15 E001

Simulation of waveguide coupled single and double layer graphene electro-optic modulators — •Pawan Kumar Dubey[1], Ashraful Islam Raju[1], Rasuole Lukose[1], Christian Wenger[1,2], and Mindaugas Lukosius[1] — [1]IHP- Leibniz Institut für innovative Mikroelektronik, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]BTU Cottbus Senftenberg, Platz der Deutschen Einheit 1, 03046 Cottbus, Germany

On-chip integrated, graphene-based optical modulator has the advantages of a small device footprint, low power consumption and low drive voltage, enabling it to be used in micrometer-scale optical interconnect. One of the very first single-layer graphene modulator was experimentally demonstrated in 2011 by Liu et al.[1], with a modulation depth of 0.1db/μm and a 3dB bandwidth of 1.2 GHz. Over the decade, there have been improvements in the performance with the double-layer design, in which a dielectric layer between the two successive graphene layers was introduced. It has the potential to significantly improve modulation depth, modulation efficiency and bandwidth of the operation. In this study, we present simulated results about, ridge and buried waveguide coupled double layer graphene modulators along with the effect of material and thickness of spacer layer between two graphene layers. Our simulation demonstrates a modulation depth of, 0.17db/μm, which is 70% higher than the single-layer design. We also demonstrate a 3dB bandwidth of 40 GHz and power consumption less than 1Pj/bit.

Q 25.7 Wed 12:30 E001

Contactless sheet resistance measurements of thin III-V semiconductors by far-field terahertz reflectometry — •Konstantin Wenzel, Steffen Breuer, Robert B. Kohlhaas, and Lars Liebermeister — Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany

Measuring the electrical properties of thin semiconductor layers is crucial for the development of semiconductor devices. 4-point measurements, such as van-der-Pauw and Hall, determine these properties very accurately. However, since this method requires electrical contacts, the measurement location becomes unusable for further processing. At the same time, areas of the sample used for processing are not measured. Here, we present far-field terahertz (THz) reflectometry measurements as a contactless alternative for determining the sheet resistance with spatial resolution. We investigate various doped indium gallium arsenide samples epitaxially grown on indium phosphide substrates using THz time-domain spectrometry. We compare these measurements to standard 4-point measurements and discuss the limitations of our technique. The presented THz reflectometry allows non-contact and spatially resolved characterization of a broad spectrum of thin semiconductors, paving the way towards a new measurement technique for full-wafer characterization.

Q 25.8 Wed 12:45 E001

Valley polarization in pristine graphene with linearly po-

larised laser pulses — •Arkajyoti Maity, Ulf Saalmann, and Jan M. Rost — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38,01187 Dresden

Information processing using preferential excitation of one of the two energy degenerate valleys in inversion symmetry broken graphene-like systems has been achieved by circularly polarized pulses. These pulses couple differentially to the valleys which have opposite orbital angular momentum, depending on their polarization[1]. Recent studies have, however, shown that linearly polarised light pulses can generate appreciable valley polarization, even in pristine graphene, without breaking inversion symmetry at the Hamiltonian level[2]. In our presentation, we will shed some light on the general mechanisms of this process of valley polarization with ultrashort laser pulses. We also show results for the terahertz regime, in which graphene shows strong non-linear behavior, and discuss the role of electronic decoherences for such longer pulses.

[1]Di Xiao, Wang Yao, and Qian Niu. Valley-contrasting physics in graphene:Magnetic moment and topological transport. Phys. Rev. Lett., 99:236809,Dec 2007 [2]Hamed Koochaki Kelardeh, Ulf Saalmann, and Jan M. Rost. Ultrashortlaser-driven dynamics of massless dirac electrons generating valley polarization in graphene. Phys.Rev.Research, 4:L022014, Apr 2022

Q 26: Quantum Gases: Bosons III

Time: Wednesday 11:00–13:00 Location: E214

Q 26.1 Wed 11:00 E214

Emergence of damped-localized excitations in the Mott phase due to disorder — Renan Souza[1,2], •Axel Pelster[1], and Francisco dos Santos[2] — [1]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil

A key aspect of ultracold bosonic quantum gases in deep optical lattice potential wells is the realization of the strongly interacting Mott insulating phase. Many characteristics of this phase are well understood, however little is known about the effects of a random external potential on its gapped quasiparticle and quasihole low-energy excitations. In the present study we investigate the effect of disorder upon the excitations of the Mott insulating state at zero temperature described by the Bose-Hubbard model. Using a field-theoretical approach we obtain a resummed expression for the disorder ensemble average of the spectral function. Its analysis shows that disorder leads to an increase of the effective mass of both quasiparticle and quasihole excitations. Furthermore, it yields the emergence of damped states, which exponentially decay during propagation in space and dominate the whole band when disorder becomes comparable to interactions. We argue that such damped-localized states correspond to excitations of the Bose-glass phase.

Q 26.2 Wed 11:15 E214

Quantum Critical Behavior of Entanglement in Lattice Bosons with Cavity-Mediated Long-Range Interactions — •Simon B. Jäger[1,2], Shraddha Sharma[2,3], Rebecca Kraus[2], Tommaso Roscilde[4], and Giovanna Morigi[2] — [1]Physics Department, Technische Universität Kaiserslautern — [2]Theoretische Physik, Saarland University — [3]ICTP-The Abdus Salam International Center for Theoretical Physics — [4]Univ. Lyon, Ens de Lyon, CNRS, Laboratoire de Physique

We analyze the ground-state entanglement entropy of the extended Bose-Hubbard model with infinite-range interactions. This model describes the low-energy dynamics of ultracold bosons tightly bound to an optical lattice and dispersively coupled to a cavity mode. The competition between on-site repulsion and global cavity-induced interactions leads to a rich phase diagram, which exhibits superfluid, supersolid, and insulating phases. We use a slave-boson treatment of harmonic quantum fluctuations around the mean-field solution and calculate the entanglement entropy across the phase transitions. At commensurate filling, the insulator-superfluid transition is signaled by a singularity in the area-law scaling coefficient of the entanglement entropy, which is similar to the one reported for the standard Bose-Hubbard model. Remarkably, at the continuous $\mathbb{Z}_2$ superfluid-to-supersolid transition we find a critical logarithmic term, regardless of the filling. This behavior originates from the appearance of a roton mode in the excitation and entanglement spectrum, becoming gapless at the critical point, and it is characteristic of collective models.

Q 26.3 Wed 11:30 E214

Out of equilibrium dynamical properties of Bose-Einstein condensates in ramped up weak disorder — •Milan Radonjić[1,2], Rodrigo P. A. Lima[3,4], and Axel Pelster[4] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]GISC and GFTC, Instituto de Física, Universidade Federal de Alagoas, Maceió AL, Brazil — [4]Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Germany

We investigate theoretically how the superfluid and the condensate deformation of a weakly interacting ultracold Bose gas evolve during the ramping up of an external weak disorder potential. Both resulting deformations turn out to consist of two distinct contributions, namely a reversible equilibrium one [1,2], as well as a non-equilibrium dynamical one, whose magnitude depends on the details of the ramping protocol [3]. For the specific case of the exponential ramping up protocol, we are able to derive analytic time-dependent expressions for the aforementioned quantities. After sufficiently long time, the steady state emerges that is generically out of equilibrium. We make the first step in examining its properties by studying the relaxation dynamics into it. Also, we investigate the two-time correlation function and elucidate its relation to the equilibrium and the dynamical part of the condensate deformation. [1] K. Huang and H.-F. Meng, Phys. Rev. Lett. 69, 644 (1992). [2] B. Nagler, M. Radonjić, S. Barbosa, J. Koch, A. Pelster, and A. Widera, New J. Phys. 22, 033021 (2020). [3] M. Radonjić and A. Pelster, SciPost Phys. 10, 008 (2021)

Q 26.4 Wed 11:45 E214

Quantum phase transitions of excited states in spinor BECs — •Bernd Meyer-Hoppe[1], Fabian Anders[1], Polina Feldmann[2,3], Luis Santos[2], and Carsten Klempt[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [2]Leibniz Universität Hannover, Institut für Theoretische Physik, Appelstraße 2, 30167 Hannover, Germany — [3]Stewart Blusson Quantum Matter Institute, The University of British Columbia, 2355 East Mall, Vancouver BC V6T 1Z4, Canada

Depending on external control parameters, the physically realized states of a given system can be grouped into phases that are defined by a measurable order parameter. For ultracold systems, where quantum fluctuations dominate thermal ones, quantum phases arise, which are separated by quantum phase transitions (QPTs) with a vanishing energy gap between the ground state and the first excited state. Today, ultracold quantum many-body systems can also be prepared at non-zero energy without thermalization. For such systems, it is possible to define excited-state quantum phase transitions (ESQPTs) by an analogous divergence of the density of states.

Here we present the experimental determination of a quantum phase diagram in a spinor BEC, where the energy of the system is one of the control parameters. The quantum phases are detected by the measurement of an interferometric order parameter that abruptly changes at the ESQPTs. We identify three quantum phases and their transitions by varying two control parameters: the effective magnetic field and the excitation energy.

Q 26.5 Wed 12:00 E214

Hartree-Fock Analogue Theory for Thermo-Optic Interaction — •Enrico Stein und Axel Pelster — Physics Department and Research Centre OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger-Straße 46, 67663 Kaiserslautern

Photon Bose-Einstein condensates are created in a microcavity filled with a dye solution in which photons are trapped. The dye continually absorbs and re-emits these photons causing the photon gas to thermalise at room temperature and finally to form a Bose-Einstein condensate. Because of a non-ideal quantum efficiency, these cycles heat the dye solution, creating a medium in which effective photon-photon interaction takes place. However, a full Hamiltonian formulation of this process has yet to be derived.

In this talk, we focus on a Hamiltonian description of the effective photon-photon interaction that includes the thermal cloud and, thus, resembles a Hartree-Fock analogue theory for this kind of interaction. Using an exact diagonalisation approach, we work out how the effective photon-photon interaction modifies the spectrum of the photon gas and how it affects the condensate width. As a second case study, we apply our theory to the dimensional crossover from 2D to 1D. In this scenario, we focus on a comparison with a plain variational approach based on the Gross-Pitaevskii equation and explicitly work out the contribution of the thermal cloud.

Q 26.6 Wed 12:15 E214

Condensate formation in a dark state of a driven atom-cavity system — •Jim Skulte[1,2], Phatthamon Kongkhambut[1], Hans Kessler[1], Jayson G. Cosme[3], Andreas Hemmerich[1,2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany. — [3]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

An intriguing class of quantum states in light-matter systems are the so-called dark states. We demonstrate condensate formation in a dark state in an ultracold quantum gas coupled to a high-finesse cavity and pumped by a shaken optical lattice [1]. We show experimentally and theoretically that the atoms in the dark state display a strong suppression of the coupling to the cavity. On the theory side, this is supported by solving the dynamics of a minimal three-level model [2] and of the full atom-cavity system. The symmetry of the condensate wave function is anti-symmetric with respect to the potential minima of the pump lattice, and displays a staggered sign along the cavity direction. This symmetry decouples the dark state from the cavity, and is preserved when the pump intensity is switched off.

[1] J. Skulte et al., Condensate formation in a dark state of a driven atom-cavity system, arXiv:2209.03342 (2022)

[2] J. Skulte et al., Parametrically driven dissipative three-level Dicke model, PRA 127, 253601 (2021)

Q 26.7 Wed 12:30 E214

Real-Time Instantons and Self-Similar Scaling in a 1D Spin-1 Bose Gas Far from Equilibrium — •Ido Siovitz, Stefan Lannig, Yannick Deller, Helmut Storbel, Markus Oberthaler, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

A system driven far from equilibrium via a parameter quench can show universal dynamics, characterized by self-similar spatio-temporal scaling, associated with the approach to a non-thermal fixed point. The study of such universality classes may assist in a thorough investigation of many systems ranging from the post-inflationary evolution of the universe to low-energy dynamics in cold gases.

Topological excitations in the system are considered to be one of the driving mechanisms of coarsening dynamics in the system and are, as such, a point of interest in the study of far from equilibrium physics. We will discuss the infrared scaling phenomena of a one-dimensional spin-1 Bose gas quenched from the polar phase to the easy-plane phase and provide evidence of the existence of real-time instantons, appearing as vortices in space and time. The latter's contribution to the coarsening dynamics of the system will be shown, and an effective theory describing the mechanism of their appearance will be presented.

Q 26.8 Wed 12:45 E214

Condensation and Thermalization of an Easy-Plane Ferromagnet in a Spinor Bose Gas — Maximilian Prüfer[2], Daniel Spitz[3], •Stefan Lannig[1], Helmut Strobel[1], Jürgen Berges[3], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institute for Physics, Heidelberg, Germany — [2]Vienna Center for Quantum Science and Technology, Vienna, Austria — [3]Institute for Theoretical Physics, Heidelberg, Germany

Bose-Einstein condensates are ideally suited to investigate dynamical phenomena emerging in the many-body limit, such as the build-up of long-range coherence, superfluidity or spontaneous symmetry breaking. We study the thermalization dynamics of an easy-plane ferromagnet in a homogeneous one-dimensional spinor Bose gas of ^{87}Rb. This is demonstrated by the dynamic emergence of effective long-range coherence of the spin field. For a thermalized state we verify spin-superfluidity by experimentally testing Landau's criterion and reveal the structure of one massive and two massless modes, which are a consequence of explicit and spontaneous symmetry breaking, respectively. Our experiments allow us to observe the thermalization of an easy-plane ferromagnetic Bose gas. The relevant momentum-resolved observables are in agreement with a thermal prediction obtained from a microscopic model in the Bogoliubov approximation.

Prüfer et al., Nature Physics (2022), DOI: 10.1038/s41567-022-01779-6

Q 27: Ultra-cold Atoms, Ions and BEC II (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: F303

Invited Talk Q 27.1 Wed 11:00 F303

Realization of the Periodic Quantum Rabi Model in the Deep Strong Coupling Regime with Ultracold Rubidium Atoms — •Stefanie Moll[1], Geram Hunanyan[1], Johannes Koch[1], Enrique Rico[2,3], Enrique Solano[2,3], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, 48009 Bilbao, Spain

At moderate coupling strengths, the interaction of light and matter is well described in terms of the Jaynes-Cummings model. However, when the coupling strength approaches the optical resonance frequency, the system enters the deep strong coupling regime, where the full quantum Rabi Hamiltonian applies, leading to non-intuitive dynamics.

In our experiment we realize the quantum Rabi model using ultracold Rubidium atoms in an optical lattice potential, creating an effective two-level system, here encoded in different Bloch bands. The bosonic mode is represented by the oscillation of atoms in a superimposed optical dipole trapping potential.

We observe atomic dynamics in the deep strong coupling regime with the cold atoms system. At long interaction times we observe collapse and revival of the initial state, as can be described within the so-called periodic quantum Rabi model.

Q 27.2 Wed 11:30 F303

Metastable phases in spinor Bose-Einstein condensates at finite temperatures — •Eduardo Serrano-Ensástiga[1,2] and Francisco Mireles[1] — [1]Departamento de Física, Centro de Nanociencias y Nanotecnología, Universidad Nacional Autónoma de México, Ensenada, Baja California, México — [2]Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, University of Liège, Liège, Belgium

Spinor Bose-Einstein condensates (BEC) with the spin as a degree of freedom have been studied intensively since its first experimental realization in 1998. A field with current scientific interest is the presence of metastable phases and their role in a variety of phenomena, such as domain formation, quench dynamics, or quantum dynamical phase transitions, among others. In this talk, we present the metastable spin-phase diagrams of a spinor BEC at finite temperatures for spin 1 and 2. The resulting phase diagrams offer further insights of the different quench dynamics observed in experiments, and they allow us to infer similar quench processes due to a sudden change in the temperature or other external fields. Our approach starts with the Hartree-Fock (HF) approximation but takes advantage of the common symmetries between the Hamiltonian and the order parameter. [1] E. Serrano-Ensástiga and F. Mireles, Phys. Rev. A 104, 063308 (2021). [2] E. Serrano-Ensástiga and F. Mireles, arXiv:2211.16428 (2022).

Q 27.3 Wed 11:45 F303

Ultradilute quantum liquid of dipolar atoms in a bilayer

— •Grecia Guijarro[1,2], Grigory Astrakharchik[1], and Jordi Boronat[1] — [1]Theoretische Physik, Saarland University, Campus E2.6, 66123 Saarbrücken, Germany — [2]Departament de Física, Universitat Politècnica de Catalunya, Campus Nord B4-B5, 08034 Barcelona, Spain

We show that ultradilute quantum liquids can be formed with ultracold bosonic dipolar atoms in a bilayer geometry. Contrary to previous realizations of ultradilute liquids, there is no need of stabilizing the system with an additional repulsive short-range potential. The advantage of the proposed system is that dipolar interactions on their own are sufficient for creation of a self-bound state and no additional short-range potential is needed for the stabilization. We perform quantum Monte Carlo simulations and find a rich ground state phase diagram that contains quantum phase transitions between liquid, solid, atomic gas, and molecular gas phases. The stabilization mechanism of the liquid phase is consistent with the microscopic scenario in which the effective dimer-dimer attraction is balanced by an effective three-dimer repulsion. The equilibrium density of the liquid, which is extremely small, can be controlled by the interlayer distance. From the equation of state, we extract the spinodal density, below which the homogeneous system breaks into droplets. Our results offer a new example of a two-dimensional interacting dipolar liquid in a clean and highly controllable setup.

Q 27.4 Wed 12:00 F303

strongly-interacting bosons at 2D-1D dimensional crossover — •Hepeng Yao, Lorenzo Pizzino, and Thierry Giamarchi — DQMP, University of Geneva, 24 Quai Ernest-Ansermet, CH-1211 Geneva, Switzerland

Quantum gases at dimensional crossover exhibit fruitful physics which reflects fascinating properties of non-integer dimensions. While various fascinating researches have been carried out in the tight-binding limit [1,2], the smooth dimensional crossover for strongly-interacting ultracold bosons in continuous lattice, which is strongly adapted to current generation of experiments, is rarely studied. In this talk, I will present our study about strongly-interacting bosons under continuous potential at 2D-1D dimensional crossover [3]. Using quantum Monte Carlo calculations, we investigate this dimensional crossover by computing longitudinal and transverse superfluid fractions as well as the superfluid correlation as a function of temperature, interactions and potential. Especially, we find the correlation function evolves from a Berezinskii-Kosterlitz-Thouless (BKT) to Tomonaga-Luttinger liquid (TLL) type, with the coexistence of 2D and 1D behaviors appearing at the dimensional crossover. In the end, I will discuss the consequences of these findings for cold atomic experiments

[1]. M. Cazalilla, A. Ho, and T. Giamarchi, New Journal of Physics 8(8), 158 (2006)

[2]. G. Bollmark, N. Laflorencie, and A. Kantian, Phys. Rev. B 102, 195145 (2020)

[3]. H. Yao, L. Pizzino, T. Giamarchi, arXiv:2204.02240(2022)

Q 27.5 Wed 12:15 F303

Making statistics work: a quantum engine in the BEC-BCS crossover — •Jennifer Koch[1], Keerthy Menon[2], Eloisa Cuestas[2], Sian Barbosa[1], Eric Lutz[3], Thomás Fogarty[2], Thomas Busch[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]OIST Graduate University, Onna, Okinawa, Japan — [3]Institute for Theoretical Physics I, University of Stuttgart, Germany

Heat engines convert thermal energy into mechanical work both in the classical and quantum regimes. However, quantum theory offers genuine nonclassical forms of energy, different from heat, which so far have not been exploited in cyclic engines to produce useful work. In this talk, we present the experimental realization of a novel quantum many-body engine fuelled by the energy difference between fermionic and bosonic ensembles of ultracold particles that follows from the Pauli exclusion principle. We employ a harmonically trapped superfluid gas of ^{6}Li atoms close to a magnetic Feshbach resonance which allows us to effectively change the quantum statistics from Bose-Einstein to Fermi-Dirac. We replace the traditional heating and cooling strokes of a quantum Otto cycle by tuning the gas between a Bose-Einstein condensate and a unitary Fermi gas (and back) through a magnetic field. In the talk, we will focus on the quantum nature of such a Pauli engine, which is revealed by contrasting it to a classical thermal engine and to a purely interaction-driven device. Our findings establish quantum statistics as a useful thermodynamic resource for work production.

[1] Koch, J. et al. arXiv: 2209.14202 (2022)

Q 27.6 Wed 12:30 F303

Induced interaction between ionic polarons in condensates — •Luis Ardila — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

In this talk, we will discuss ionic polarons and their induced interaction created as a result of charged particles interacting with a Bose-Einstein condensate. Here we show that even in a comparatively simple setup consisting of charged impurities in a weakly interacting bosonic medium with tunable atom-ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state. Using quantum Monte Carlo simulations, we unravel its vastly different polaronic properties compared to neutral quantum impurities. Moreover, we identify a transition between the regime amenable to conventional perturbative treatment in the limit of weak atom-ion interactions and a many-body bound state with vanishing quasi-particle residue composed of hundreds of atoms. Contrary to the case of neutral impurities, ionic polarons can bound many excitations and bosons from the condensate, forming many-body bound-states and changing the ground-state properties of the polaron radically. Also, transport properties are accessible by using external electric fields. Finally, we investigate the specific case of two ions that mediate interactions via the bosonic bath. This interaction can be sizable with respect to the Coulomb interaction, giving rise to notable effects which may have direct consequences in the platform employed for future quantum technologies.

Q 27.7 Wed 12:45 F303

Observation of Universal Hall Response in Strongly Interacting Fermions — •Tianwei Zhou[1], Giacomo Cappellini[2,3], Daniele Tusi[2], Lorenzo Franchi[1], Jacopo Parravicini[1,2,3], Massimo Inguscio[2,3], Jacopo Catani[2,3], and Leonardo Fallani[1,2,3] — [1]Department of Physics and Astronomy, University of Florence, 50019 Sesto Fiorentino, Italy — [2]LENS, 50019 Sesto Fiorentino, Italy — [3]CNR-INO, 50019 Sesto Fiorentino, Italy

I will present the recent experiment performed at University of Florence with ultracold 173Yb Fermi gases in optical lattices, in the presence of momentum-dependent Raman coupling between different internal states [1] and strong atom-atom interactions.

Specifically, I will report on the first quantum simulation of the Hall effect for strongly interacting fermions [2]. By performing direct measurements of current and charge polarization in an ultracold-atom simulator, we trace the buildup of the Hall response [3] in a synthetic ladder pierced by a magnetic flux, going beyond stationary Hall voltage measurements in solid-state systems. We witness the onset of a clear interaction-dependent behavior, where the Hall response deviates significantly from that expected for a non-interacting electron gas, approaching a universal value. Our system, able to reach hard to compute regimes also demonstrates the power of quantum simulation for strongly correlated topological states of matter.

References [1] M. Mancini et al., Science 349, 1510 (2015). [2] T.-W. Zhou et al., arXiv:2205.13567 (2022). [3] S. Greschner et al., Phys. Rev. Lett. 122, 083402 (2019).

Q 28: Quantum Technologies: Trapped Ions (joint session Q/QI)

Time: Wednesday 11:00–13:00 Location: F342

Q 28.1 Wed 11:00 F342

Non-commuting dynamics in light-ion-interactions on an ion-trap system — •Sebastian Saner[1], Oana Bazavan[1], Donovan Webb[1], Gabriel Araneda[1], Mariella Minder[1], David Lucas[1], Raghavendra Srinivas[1], and Chris Ballance[1,2] — [1]University of Oxford, Oxford, UK — [2]Oxford Ionics, Oxford, UK

The interaction Hamiltonian that governs the dynamics between trapped ions and laser light [1] is well studied and understood in the limit of low laser powers, leading to simple dynamics. However, at high powers, off-resonant coupling to multiple carrier and motional transitions is not negligible, leading to more complex and richer dynamics, with Hamiltonians exhibiting non-commuting terms.

In quantum computing with trapped ions, fast and versatile interactions that require high laser powers are important. It is of interest to either suppress those off-resonant terms or harness them in a controlled way. In this talk, we present our experimental work on utilising non-commuting terms to create two-qubit entanglement [2]. Furthermore, we evaluate how to apply this idea in the context of hybrid spin-motion systems. Secondly, we will show how we employ a phase stable optical lattice to coherently suppress a non-commuting error source that appears in the conventional Molmer-Sorensen interaction. This approach has the potential to allow for fast and high-fidelity entangling gates which are not limited by scattering errors.

[1]: Wineland et al., J. Res. Natl. Inst. Stand. Technol. 103(3), 259-328, 1998

[2]: Bazavan, Saner et al., arXiv:2207.11193, 2022

Q 28.2 Wed 11:15 F342

Optimization methods for RF junctions in register-based surface-electrode ion traps — •Florian Ungerechts[1], Rodrigo Munoz[1], Axel Hoffmann[1,2], Brigitte Kaune[1], Teresa Meiners[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Register-based ion traps are among the leading approaches for scalable quantum processors. A fundamental component of these are RF junctions that allow the ions to move between the specialized zones of the quantum processor via ion transport. We discuss the design choices and optimization methods of such a junction and present an optimized symmetric RF X-junction feasible for through-junction ion transport of single $^{9}Be^{+}$ ions and multilayer microfabrication.

Q 28.3 Wed 11:30 F342

Simultaneous super- and subradiant light emission of two stored ion in free space — •Stefan Richter[1], Sebastian Wolf[2], Joachim vom Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany

Modification of spontaneous decay in space and time is a central topic of quantum physics. It has been predominantly investigated in cavity quantum electrodynamic systems. Altered spontaneous decay may equally result from correlations among the emitters in free space, as observed in super- and subradiance. Yet, preparation of an entangled quantum state and the resulting modified emission pattern has not been observed so far due to the lack of ultra-fast multi-pixelated cameras. Using two trapped ions in free space, we prepare their state via projective measurements and observe their corresponding collective photon emission. Depending on the direction of detection of the first photon, we record fundamentally different emission patterns, including super- and subradiance [1]. Our results demonstrate that the detection of a single photon may fundamentally determine the subsequent collective emission pattern of an atomic array, here represented by its most elementary building block of two atoms stored in an ion trap.

[1] arXiv:2202.13678

Q 28.4 Wed 11:45 F342

Quantum repeater node with two $^{40}Ca^{+}$ ions — •Max Bergerhoff, Omar Elshehy, Stephan Kucera, Matthias Kreis, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The quantum repeater cell according to [1] is a fundamental building block for large distance quantum networks. It serves for overcoming the exponential scaling of fiber transmission, by the division of a transmission fiber in two asynchronously driven segments and the use of quantum memories. Recent realizations with single atoms [2] in a cavity and ions in a large cavity [3] already demonstrate the advantage of this protocol. Here we report on the implementation of a free-space quantum repeater cell with two $^{40}Ca^{+}$ ions in the same trap that act as memories.

We demonstrate ion-photon entanglement according to [4] by controlled emission of single photons from the individually addressed ions. The entanglement is swapped onto the photons via the Mølmer-Sørensen gate [5]. We discuss the rate scaling due to the asynchronous sequence and the fidelity of the final photon-photon state.

[1] D. Luong et al., Appl. Phys. B 122, 96 (2016)

[2] S. Langenfeld et al., Phys. Rev. Lett. 126, 30506 (2021)

[3] V. Krutyanskiy et al. arXiv preprint arXiv:2210.05418 (2022)

[4] M. Bock et al., Nat. Commun. 9, 1998 (2018)

[5] K. Mølmer and A. Sørensen, Phys. Rev. Lett 82, 1835-8 (1999)

Q 28.5 Wed 12:00 F342

Spin-dependent coherent light scattering from linear ion crystal — •Maurizio Verde[1], Benjamin Zenz[1], Stefan Richter[2], Zyad Shehata[2], Ferdinand Schmidt-Kaler[1], and Joachim von Zanthier[2] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]Institut für Optik, Information und Photonik, Universität Erlangen, Erlangen, Germany

Linear crystals of ultracold ions are emerging platforms for quantum simulator thanks to their unique properties of long coherence times and high-fidelity optical manipulation. In this perspective, the development of new detection techniques based on photo-correlation measurements is of central interest in order to access structural and dynamical information. Following the ideas reported in [1] on light-crystal coherent scattering, we explored extensions of these phenomena and here we report on a new detection scheme to unveil the spin texture for linear chains of $^{40}Ca^{+}$ ions. First, we initialize the crystal in the desired spin configuration, then we use the narrow transitions at 729nm and 854nm to perform spin-dependent coherent scattering and measure the background-free $g^{(1)}$ photo-correlation function by recording light near 393nm in the far field. The laser beam geometry is chosen to minimize the single-ion recoil and therefore the corresponding Debye-Waller factor. We use a high spatio-temporal resolution MCP camera and reveal from the spatial interference pattern the spin texture of the crystal. We discuss the efficiency of our new method for detecting magnetic phases and phase transitions.

[1]Wolf et al., Phys. Rev. Lett. 116, 183002 (2016)

Q 28.6 Wed 12:15 F342

Sideband Thermometry on Ion Crystals — •Ivan Vybornyi[1], Laura Dreissen[2], Daniel Vadlejch[2], Tanja Mehlstäubler[2], and Klemens Hammerer[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2,30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100,308116 Braunschweig, Germany

Crystals of ultracold trapped ions reach sizes of hundreds of individual particles and require high level of control over their motional temperature to account for the second-order Doppler shift in clocks and implement high-fidelity quantum gates in quantum computers. The existing thermometry tools fail to provide an accurate temperature estimation for large ground-state cooled crystals, either focusing only on the symmetric c.o.m. mode of motion or neglecting the involved spin-spin correlations between the ions.

To resolve the thermometry large-N bottleneck, we consider crystal many-body dynamics arising when motional sideband transitions are driven in a near ground-state regime, which is a widely used approach in thermometry of a single ion. To gain some valuable insights on the sideband thermometry method, we also address the single ion case and study it from the Fisher Information prospective.

Extending the approach further, we account for entanglement created between the ions in a crystal to derive a new reliable temperature estimator, insensitive to the number of ions, and field-test in experiments with 4- and 19-ion crystals done by colleagues from PTB and Innsbruck.

Q 28.7 Wed 12:30 F342

Mixed qubit types in registers of trapped barium ions — •Fabian Pokorny, Andres Vazquez-Brennan, Jamie Leppard, Ana Sotirova, and Chris Ballance — Department of Physics, University of Oxford, United Kingdom

Registers of mixed qubit types are a promising approach for scaling trapped-ion quantum computers. The insensitivity of one qubit type to the others' light fields eliminates scattering errors and enables advanced qubit control schemes.

Barium-ion qubits are uniquely suited for realising this approach. Their long-lived metastable states allow for the implementation of different qubit types using just one atomic species, which, combined with atomic transitions in the visible range, significantly reduces experimental complexity [1]. In our experiment we use $^{137}Ba^{+}$, whose nuclear spin of 3/2 provides magnetic-field insensitive 'clock' qubits in both the stable ground-state manifold and the long-lived metastable $5D_{5/2}$ manifold. The ground and metastable level qubits are connected via a pair of 'clock' transitions, and both qubit types can be driven using a two-photon Raman process with 532 nm light and low scattering error.

We show an all-fiber Raman system capable of single-ion addressing in a large qubit register and further demonstrate simultaneous manipulation of ground-state and metastable-state qubits. These are prerequisites for working with long registers of mixed qubit types and for realising partial projective measurements and mid-circuit measurements.

[1] D. Allcock et al., Applied Physics Letters, vol. 119, 2021.

Q 28.8 Wed 12:45 F342

Introducing a surface ion trap with integrated photonics for Yb+ ions — •Markus Kromrey[1], Elena Jordan[1], Guochun Du[1], Carl-Frederik Grimpe[1], Gillenhaal Beck[2], Karan Metha[5], and Tanja Mehlstäubler[1,3,4] — [1]Physikalisch Technische Bundesanstalt, Braunschweig, Deutschland — [2]Eidgenössische Technische Hochschule Zürich, Zürich, Schweiz — [3]Laboratorium für Nano- und Quantenengineering, Hannover, Deutschland — [4]Leibniz Universität Hannover, Hannover, Deutschland — [5]Cornell University, Ithaca, USA

One of the main obstacles to the scalability of ion trap applications such as quantum computing and quantum sensing is the miniaturization and scalability of the optics required to provide the trapped ions with the light necessary to manipulate them. In this talk, we will present a surface ion trap with integrated optics that requires much less space than classical setups. Integrated optics also offer routes to eliminating important technical noise sources present in conventional setups. The integrated optics deliver all the lasers required for a Yb 172 clock experiment to the ion. One of the main features of the trap is a grating coupler that provides the ion with light in a Hermite-Gaussian mode to excite the narrow Yb 172 octupole transition.

Q 29: Implementations: Ions and Atoms (joint session QI/Q)

Time: Wednesday 11:00–13:00 Location: F428

Invited Talk Q 29.1 Wed 11:00 F428

Experimental quantum error correction with trapped ions — •Philipp Schindler — University of Innsbruck

For large-scale quantum computing, effective quantum error correction will be mandatory. Current, small-scale experiments can be used to validate assumptions on the physical errors in the system that are required for fault-tolerant operation. I will report on our experimental efforts towards fault-tolerant quantum information processing in our trapped-ion platform. In particular, I will discuss the implementation of a fault tolerant universal set of logical operations. The results from these experiments are used to inform the development of large scale ion-trap quantum devices.

Q 29.2 Wed 11:30 F428

Towards an entangling gate between bosonic qubits in trapped ions — •Stephan Welte, Martin Wagener, Moritz Fontbote-Schmidt, Hendrik Timme, Luca Hermann, Ralf Berner, Edgar Brucke, Paul Röggla, Ivan Rojkov, Florentin Reiter, and Jonathan Home — ETH Zurich, Zurich, Switzerland

Encoding quantum information in a harmonic oscillator provides a resource-efficient platform for quantum error correction. A promising code is Gottesman-Kitaev-Preskill (GKP) encoding [1], which has been realized both in trapped ions [2, 3] and superconducting qubits [4]. State preparation, single qubits rotations, readout, and error correction have been realized in both architectures. However, a universal two-qubit gate has not yet been realized. We will describe our work on such an entangling gate between GKP qubits prepared in the motional modes of calcium ions in a Paul trap. The modes are coupled via the Coulomb interaction approximating a beam splitter interaction. Together with squeezing operations, this interaction can realize the desired universal gate. In theoretical work, we investigate this gate for experimentally realistic parameters and finite energy states. In parallel, we are developing an apparatus for an experimental implementation, including the fabrication of a novel ion trap and the implementation of individual addressing with tightly focused laser beams.

[1] D. Gottesman, A. Kitaev, and J. Preskill. PRA 64, 012310 (2001) [2] C. Flühmann et al. Nature 566, 513(2019) [3] B. de Neeve et al. Nat. Phys. 18, 296 (2022) [4] V. Sivak et al. arXiv 2211.09116 (2022)

Q 29.3 Wed 11:45 F428

A universal two-qubit computational register for trapped-ion quantum processors — •Nicolas Pulido-Mateo[1,2], Hardik Mendpara[1,2], Markus Duwe[1,2], Giorgio Zarantonello[1,2,3], Amado Bautista-Salvador[1,2], Ludwig Krinner[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA

Here we report on the realization of a two qubit universal computational register compatible with the QCCD architecture [1]. Single qubit gates are performed by addressing each ion individually via a micromotion sideband [2]. The entangling operation is implemented using an MS-type interaction, where we measure an infidelity that approaches 10^{-3} [3] when using partial state tomography. To characterize the single qubit gates we use a randomized benchmarking protocol [4] and obtain an infidelity of $3.8(4) \times 10^{-3}$. We perform a characterization of the register by means of the cycle benchmarking protocol [5] obtaining, as a preliminary result, a composite process fidelity of 96.6(4) %. Finally we use simulation software for quantum open systems to model possible error sources and calculate an error budget.

[1] D. Kielpinski *et al.*, Nature **417**, 709 (2002).
[2] U. Warring *et al.*, Phys. Rev. Lett. **17**, 173002 (2013)
[3] M. Duwe *et al.*, Quantum Sci. Technol. **7**, 045005 (2022)
[4] C. Piltz *et al.*, Nature Communications **5**, 4679 (2014).
[5] A. Erhard *et al.*, Nat. Commun. **10**, 5347 (2019)

Q 29.4 Wed 12:00 F428

Coherent Control of Trapped Ion Qubits with Localized Electric Fields — •Raghavendra Srinivas[1,2], Clemens Löschnauer[1], Maciej Malinowski[1], Amy Hughes[1], Rustin Nourshargh[1], Vlad Negnevitsky[1], David Allcock[1,3], Steven King[1], Clemens Matthiesen[1], Thomas Harty[1], and Chris Ballance[1,2] — [1]Oxford Ionics — [2]University of Oxford — [3]University of Oregon, Eugene

We present a new method for coherent control of trapped ion qubits in separate interaction regions of a multi-zone trap by simultaneously applying an electric field and a spin-dependent gradient. Both the phase and amplitude of the effective single-qubit rotation depend on the electric field, which can be localised to each zone. We demonstrate this interaction on a single ion using both laser-based and magnetic field gradients in a surface-electrode ion trap, and measure the localisation of the electric field.

[1] arXiv:2210.16129

Q 29.5 Wed 12:15 F428

Entangling scheme for Rydberg ion crystals using electric kicks in radial direction — •Han Bao[1], Jonas Vogel[1], Alexander Schulze-Makuch[1], Ulrich Poschinger[1], and Ferdinand Schmidt-Kaler[1,2] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

Due to the strong dipole interaction between Rydberg atoms, fast entangling gates have been achieved both in neutral atoms [1] and trapped ions [2]. A second unique feature of Rydberg states is their high electric polarizability. For trapped ions, Rydberg states electric polarizability may lead to a change of the secular frequency [3]. Such state dependent secular frequency can establish entanglement [4]. Here, we show that using electric kicks in the radial direction demands a 100 times lower voltage, thus much more feasible for an experimental realization. Accordingly, as lower motional are transiently excited only, the scheme becomes more robust. We also show scaling the method up for larger ions crystals, using a complex sequence of electric kicks, such that finally the motion state is recovered back.

We discuss the status of the experimental realization the electric kick entanglement generation.

[1]Levine et al., *Phys. Rev. Lett.* **123**, 170503 (2019)
[2]Zhang et al., *Nature* **580**, 345 (2020)
[3]Schmidt-Kaler et al., *New J. Phys.* **13**, 075014 (2011)
[4]Vogel et al., *Phys. Rev. Lett.* **123**, 153603 (2019)

Q 29.6 Wed 12:30 F428

Coherent transfer of transverse optical momentum to the motion of a single trapped ion — •Felix Stopp[1], Maurizio Verde[1], Milton Katz[2], Martín Drechsler[2], Christian Schmiegelow[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]CONICET, Instituto de Física de Buenos Aires (IFIBA), Universidad de Buenos Aires, Buenos Aires, Argentina

A structured light beam is carrying orbital angular momentum and we demonstrate the excitation of the center of mass motion of a single atom in the transverse direction to the beam's propagation. This interaction is achieved with a vortex beam carrying one unit of orbital angular momentum and one unit of spin angular momentum. Using a singly charged $^{40}Ca^+$ ion, cooled near the ground state of motion in the three-dimensional harmonic potential of a Paul trap, we probe the sidebands of the $S_{1/2}$ to $D_{5/2}$ transition near 729 nm to quantify the momentum transfer. Exchange of quanta in the perpendicular direction to the beam's wave vector k is observed in case of centered a vortex shaped beam, while parasitic carrier excitation is reduced by a factor 40. This is in sharp contrast to the vanishing spin-motion coupling at the center of Gaussian beam. We characterize the coherent interaction by an effective transverse Lamb-Dicke factor $\eta_\perp^{\mathrm{exp}} = 0.0062(5)$ which is in agreement with our theoretical prediction $\eta_\perp^{\mathrm{theo}} = 0.0057(1)$ [1]. Finally we discuss the application of our finding for quantum information processing with trapped ion crystals.

[1] accepted Paper 22 November 2022: Phys. Rev. Lett.

Q 29.7 Wed 12:45 F428

Lasersystem for Control of Magnsium Atoms — •Tobias Spanke, Lennart Guth, Philip Kiefer, Lucas Eisenhart, Deviprasath Palani, Apurba Das, Florian Hasse, Jörn Denter, Mario Niebuhr, Ulrich Warring, and Tobias Schätz — Physikalisches Institut, Albert-Ludwigs-Universität, Freiburg

Trapped ions present a promising platform for quantum simulations. Versatile and robust laser systems with narrow bandwidth and high power and intensity stability are required for reliable control of this platform. The latest systems for Mg^+, Be^+ ions are based on vertical external cavity surface emitting lasers (VECSEL)[1] in the near-infrared. We are testing new compact cooling systems with impact on short-term frequency stability using commercially available PC parts. With the goal of measuring magnesium ions at a frequency stability of 200 kHz ($\lambda \approx 1120$ nm, P=2 W) with high accuracy. We aim at further development of the VECSEL into a compact, stable and user-friendly "turnkey" system.

[1]Burd, S. et al.(2016), VECSEL systems for generation and manipulation of trapped magnesium ions, Optica Vol. 3, Issue 12, pp. 1294-1299 (2016)

Q 30: Nano-optics

Time: Wednesday 11:00–13:00 Location: F442

Q 30.1 Wed 11:00 F442

A Novel Approach to Nanophotonic Black-Box Optimization Through Reinforcement Learning — •Marco Butz[1], Alexander Leifhelm[1], Marlon Becker[2], Benjamin Risse[2], and Carsten Schuck[1] — [1]Center for Soft Nanoscience, Münster, Germany — [2]Institute for Geoinformatics, University of Münster, Germany

After the use of Photonic integrated circuits (PICs) has led to a significant increase in the performance of devices employed in classical telecommunication schemes in the last years, complex quantum optics experiments have recently undergone a similar transition from free space setups to PICs. This development poses challenging requirements on the PICs' individual components in both footprint and performance and even raises the need for novel functionalities that are not accessible by conventional design methods. Recently, various design algorithms addressing this problem have been demonstrated. However, they all suffer from various drawbacks such as reliance on convex optimization methods in non-convex environments or the presence of gradient fields, which cannot always be accessed easily. Here, we show a novel inverse-design method based on reinforcement learning capable of producing pixel-discrete nanophotonic devices with arbitrary functionality and small footprints. Freely configurable design constraints can be realized through multiple interfaces enabling manipulation of the internal data flow. To demonstrate the capabilities of our method we show the fully automated design of a silicon-on-insulator waveguide-mode converter with $> 95\%$ conversion efficiency from scratch.

Q 30.2 Wed 11:15 F442

Reentrant delocalization transition in one-dimensional photonic quasicrystals — Sachin Vaidya[1], •Christina Jörg[1,2], Kyle Linn[2], Megan Goh[3], and Mikael C. Rechtsman[1] — [1]Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA — [2]Physics Department and Research Center OPTIMAS, TU Kaiserslautern, D- 67663 Kaiserslautern, Germany — [3]Department of Physics, Amherst College, Amherst, MA 01002, USA

Over the past few years, there has been significant interest in exploring the localization of waves propagating in disordered media, also known as Anderson localization. We experimentally demonstrate that the localization transition in certain one-dimensional photonic quasicrystals (PhQC) is followed by a surprising second delocalization transition upon further increasing quasiperiodic disorder strength - an example of a reentrant transition. We measure this localization and reentrant delocalization via the inhibition and complete recovery of transmission through an Aubry-André type PhQC for increasing quasiperiodic modulation. To further shed light on the observed reentrant transition, we also develop a tight-binding model inspired by the PhQCs that captures the essential localization physics of our system.

Q 30.3 Wed 11:30 F442

Nonlocal Soft Plasmonics: Ionic plasmon effects in planar homogeneous multi-layered systems — •Preethi Ramesh Narayan and Christin David — Institute of Condensed Matter Theory and Optics (IFTO), Abbe Center of Photonics, Friedrich-Schiller-University Jena (FSU Jena), Jena, Germany

Plasmonics is the study of resonant interactions between free electrons present in the conduction band of metals and incident electromagnetic radiation. These resonant interactions result in surface plasmon waves that propagate along the surface at the metal-dielectric interface. Apart from metals, such charge oscillations can also be found in soft matter as a charged ionic fluid in an impermeable lipid membrane. Such a system can be studied analogously from the behavior of metal nanosystems, with lower resonance frequencies in larger ionic systems. We study the ionic plasmon interactions in planar electrolyte systems. We also consider the nonlocal interactions between the charge carriers that happen due to strong spatial confinement on the microscale. The optical response of free positive and negative ions in an electrolyte is explained using a hydrodynamic, two-fluid model under the scope of nonlocality. These ions oscillate with different bulk plasmon frequencies based on their respective charge, mass, and concentration. This allows analyzing the nonlocal plasmonic effects through highly tunable system parameters. We develop this system further with the aim to understand energy transfer in nerve cells and electrolyte-solid interactions for photocatalysis.

Q 30.4 Wed 11:45 F442

Nonlinear response in nanostructured multilayers — •Navid Daryakar[1] and Christin David[2] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

We studied the nonlinear optical response of composite nanostructured layers in terms of a self-phase-modulated, third-order Kerr nonlinearity. Theoretical modeling is considered through effective medium theories (Maxwell-Garnett, Bruggeman) to identify the behavior of the composite nanostructures in linear and nonlinear regimes. The optical response is modified and the dependence on various system parameters such as fill fraction, layer thickness and width, diffraction orders and laser intensity is studied. We thus show at which intensity transitioning to the nonlinear regime occurs, and how material response changes can be conveniently used as a signature of the transition. Our finding is general, and the method can be applied to any material mixture of thin films. As such, we expect our results to enable future studies aimed at predicting nonlinear optical response of composite nanostructures on the nanoscale. Nonlinear effective medium theory is used to describe low densities of gold nanoparticles embedded in an equally nonlinear host material. The fill fraction strongly influences the effective nonlinear susceptibility of the materials increasing it by orders of magnitude in case of gold due to localized surface plasmonic resonances.

Q 30.5 Wed 12:00 F442

Towards Cavity-Enhanced Spectroscopy of Single Europium Ions in Yttria Nanocrystals — Timon Eichhorn, •Nicholas Jobbitt, and David Hunger — Karlsruher Institut für Technologie

A promising approach for realizing scalable quantum registers lies in the efficient optical addressing of rare-earth ion spin qubits in a solid state host. We study Eu^{3+} ions doped into Y_2O_3 nanoparticles (NPs) as a coherent qubit material and work towards efficient single ion detection by coupling their emission to a high-finesse fiber-based Fabry-Pérot microcavity. A beneficial ratio of the narrow homogeneous line to the inhomogeneous broadening of the ion ensemble at temperatures below 10 K makes it possible to spectrally address and readout single ions. The coherent control of the single ion $^5D_0$ - $^7F_0$ transition then permits optically driven single qubit operations on the Europium nuclear spin states. A Rydberg-blockade mechanism between ions within the same nanocrystal permits the implementation of a two-qubit CNOT gate to entangle spin qubits and perform quantum logic operations. We observed fluorescence signals from small ensembles of Europium ions at cryogenic temperatures and measured cavity-enhanced optical lifetimes of half the free-space lifetime resulting in effective Purcell-factors of one. Considering the low branching ratio into the desired transition this amounts to a two-level Purcell-factor of 100. We will report on the progress towards single ion readout and control.

Q 30.6 Wed 12:15 F442

Improvements of the Timing Resolution of SNSPDs Using Enhanced Light Intensity — Roland Jaha[1,2], Wolfram Pernice[3], and •Simone Ferrari[3] — [1]Institute of Physics, Münster 48149, Germany — [2]Center for Soft Nanoscience, Münster 48149, Germany — [3]Kirchhoff-Institute of Physics, Heidelberg 69120, Germany

Superconducting nanowire single-photon detectors enable single-photon detection with low dark counts, count rates up to a few Gcps, and almost unitary detection efficiency which makes them a key element in many quantum and faint light experiments. During the last few years, much effort has been spent on the development of detectors with high temporal resolution. Such devices would allow for high-speed quantum communication and the realization of optical sampling with superior bandwidth.

Typical free-space coupled low-jitter detectors suffer from low detection efficiency because of their small active region. Our nanowires instead are placed on top of a photonic waveguide where photons can be absorbed along the detector length. Using this approach, we are able to probe the detector within a confined space thereby enhancing the temporal resolution without sacrificing its detection efficiency. By adopting NbN SNSPDs atop SiN waveguides, we investigate the dependence of the temporal resolution and latency time on the photon illumination. At high photon flux, we observe an enhancement of the slew rate of the nanowire voltage response, leading to a sub-3 ps timing jitter and a reduction of the latency time of more than 100 ps compared to the single-photon level.

Q 30.7 Wed 12:30 F442

Extinction of plasmonic ellipsoidal core-shell nanoparticles — •Mathis Noell and Carsten Henkel — Institut für Physik und Astronomie, Potsdam, Germany

Plasmonic nanostructures provide an interesting platform for localized heating and field enhancement. If a nanoparticle is covert with a thin absorbing layer, theory predicts a resonance that is not seen in experimental extinction spectra. To understand this issue, we analyze the distribution of electric fields and energy dissipation in and around an ellipsoidal nanoparticle. Calculations are done for gold Nano particles covered with a few nm thick absorbing layer. At the spurious resonance the field is highly localized in this layer, suggesting that strong coupling to the molecular exciton is possible at the few-photon level. Treating the interface between the absorbing layer and the surrounding medium as a sharp interface is an assumption which is most likely not true. As a first step towards a model without a sharp layer-medium interface we modeled the layer as an effective medium (mixture of layer material and medium). Using the effective medium approach, we observe that the spurious resonance is suppressed for sufficiently diluted shells. Using a inhomogeneous but continuous permittivity profile one can formulate a model with no sharp layer-medium interface. We analyze the effective medium and continuous permittivity approaches and compare them with experimental data.

Q 30.8 Wed 12:45 F442

Tailoring Near-Field*Mediated Photon Electron Interactions with Light Polarization — •Fatemeh chahshouri and Nahid Talebi — Institute of Experimental and Applied Physics, Kiel University, 24098 Kiel, Germany

Inelastic interaction of free-electrons with optical near fields has recently attracted attention for manipulating and shaping free-electron wavepackets. Understanding the nature and the dependence of the inelastic cross section on the polarization of the optical near-field is important for both fundamental aspects and the development of new applications in quantum-sensitive measurements. Here, we investigate the effect of the polarization and the spatial profile of plasmonic near-field distributions on shaping free-electrons and controlling the energy transfer mechanisms, but also tailoring the electron recoil. We particularly show that polarization of the exciting light can be used as a control knop for disseminating the acceleration and deceleration path ways via the experienced electron recoil. We also demonstrate the possibility of tailoring the shape of the localized plasmons by incorporating specific arrangements of nanorods to enhance or hamper the transversal and longitudinal recoils of free-electrons. Our findings open up a route towards plasmonic near-fields-engineering for the coherent manipulation and control of slow electron beams for creating desired shapes of electron wavepackets.

Q 31: Precision Measurements: Atom Interferometry I (joint session Q/A)

Time: Wednesday 11:00–13:00 Location: F102

Q 31.1 Wed 11:00 F102

Ultracold matter trapped by light singularities and quantum noise. — •Alexey Okulov — Moscow, Russia

Superfluids within helical boundaries are interesting from the point of view of low dimensional physics, phase transitions and inertial sensors. The sensitivity to the ultraslow motions of reference frame is limited by an unavoidable zero-point fluctuations. The basic uncertainty relations induce the phase uncertainty by corresponding fluctuations of the particles amount in ultracold ensemble. Hopefully there exists an opportunity to reduce the phase uncertainty by means of the proper structuring of the boundaries geometry. Our aim is to present the convincing arguments in favour of usage the helical laser traps formed by the counterpropagating Laguerre-Gaussian optical vortices to reduce the restrictions on phase deviations. The evaluation of the phase uncertainty with multimode coherent states approach leads to the optimistic result that phase measurement accuracy may be improved by a factor containing 2ℓ, where ℓ is the topological charge of LG vortices, compared to the conventional nontwisted trap geometries. Recent advances in development of highly charged optical vortices with $\ell = 10^3-10^4$ open the opportunity to improve the sensitivity to reference frame slow motions by several orders of magnitude.

Q 31.2 Wed 11:15 F102

Simulating space-borne atom interferometers for Earth Observation and tests of General Relativity — •Christian Struckmann[1], Ernst M. Rasel[1], Peter Wolf[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université 61 avenue de l'Observatoire, 75014 Paris, France

Quantum sensors based on the interference of matter waves provide an exceptional performance to test the postulates of General Relativity by comparing the free-fall acceleration of matter waves of different composition. Space-borne quantum tests of the universality of free fall (UFF) promise to exploit the full potential of these sensors due to long free-fall times, and to reach unprecedented sensitivity beyond current limits.

In this contribution, we present a simulator for satellite-based atom interferometry and demonstrate its functionality in designing the STE-QUEST mission scenario, a satellite test of the UFF with ultra-cold atoms to 10^-17 as proposed to the ESA Medium mission frame [https://arxiv.org/abs/2211.15412]. Moreover, we will highlight the possibility of this simulator to design Earth Observation missions going beyond state of the art such as the CARIOQA concept [https://arxiv.org/abs/2211.01215].

This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 31.3 Wed 11:30 F102

Multi-Axis sensing utilising guided atom interferometry — •Knut Stolzenberg, Sebastian Bode, Alexander Herbst, Wei Liu, Henning Albers, Ernst Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Inertial sensors based on atom interferometry are a superior alternative to classical sensors regarding accuracy and long-term stability. Particularly in the field of autonomous navigation quantum sensors can become a viable addition to GNSS and classical IMUs. Yet the simultaneous measurement of accelerations and rotations is challenging to present experiments.

In our setup a 1064 nm crossed optical dipole trap (ODT) is used for the evaporation to quantum degeneracy. By using acousto-optical deflectors in both ODT beam paths, we add versatile control over the trapping potentials with respect to position and trap depth. This allows for the creation of one or more BECs amounting to a total number of up to 250×10^3 ultracold ^{87}Rb atoms prepared in the magnetic insensitive state $|F=1, m_F=0\rangle$. After preparation the ensembles are loaded into 1D-optical waveguides to counteract gravity and ensure radial confinement. Subsequently we span Mach-Zehnder atom interferometers utilising double-Bragg diffraction. In addition to measuring accelerations, we discuss future perspectives enabling sensitivity to gradients and rotation rates.

Q 31.4 Wed 11:45 F102

Principal Component Analysis for Image processing in Atom Interferometry — •Stefan Seckmeyer[1], Holger Ahlers[1,2], Sven Abend[1], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR) Institut für Satellitengeodäsie und Inertialsensorik„ Hannover, Germany

Image analysis plays an important role in several current state-of-the-art atom interferometry experiments. We investigate the extraction of physical quantities from absorption images of atom interferometers using principal component analysis (PCA).

As a starting point we take a simple mathematical model for the images of the output ports of a two-port atom interferometer which is using a Bose-Einstein condensate as an atom source.

We show an analytic prediction of the PCA results for a subset of parameters which allows us to ascribe physical quantities to the output of a PCA analysis. Using this method we are not only able to extract the interferometer phase for each image but also a spatial phase aberration map shared by all images, here introduced at the final beam splitter.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. 50WM2253A.

Q 31.5 Wed 12:00 F102

Systematic description of matter wave interferometers using elastic scattering in weakly curved spacetimes — •Michael Werner and Klemens Hammerer — Institut für Theoretische Physik and Institut für Gravitationsphysik (Albert-Einstein-Institut), Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We present a systematic approach to calculate all relativistic phase shift effects in Bragg-type light-pulse matter wave interferometer (MWI) experiments up to (and including) order $\mathcal{O}(c^{-2})$, placed in a weak gravitational field. The whole analysis is derived from first principles and even admits test of General Relativity (GR) apart from the usual Einstein Equivalence Principle (EEP) tests, consisting of universality of free fall (UFF) and local position invariance (LPI) deviations, by using the more general „parameterized post-Newtonian" (PPN) formalism. We collect general phase shift formulas for a variety of well-known MWI schemes and present how modern experimental setups could measure PPN induced deviations from GR without the use of macroscopic test masses. This procedure should be seen as a way to easily calculate certain phase contributions, without having to redo all relativistic calculations in new MWI setups and come up with possibly new measurement strategies.

Q 31.6 Wed 12:15 F102

3D simulations of guided BEC interferometers — •Rui Li, Stefan Seckmeyer, and Naceur Gaaloul — 1Leibniz University Hannover, Institute of Quantum Optics, Hannover, Germany

Atom interferometry (AI) has grown into a successful tool for precision measurements, inertial sensing and search for physics beyond standard model. Such high precision measurements are achieved either by large momentum transfer (LMT) or long interrogation times. Recently, the former technique has led to a state-of-the-art separation of more than 400 hbark [1]. In this experiment, Bose-Einstein Condensates (BECs) are used to further enhance precision atom interferometry due to their intrinsically strong coherence and narrow momentum width.*However, simulations of dynamics of BEC interacting with light in a generic 3D setup are limited by computation power and system sizes. In this talk, we present a newly developed numerical toolbox to solve the time-dependent Gross-Pitaevskii equation in 3D. To demonstrate its capability, we study BEC interferometers realized in both free-fall and guided geometry and compare our results with experimental data.*We specifically investigate the double-Bragg diffraction (DBD) of a BEC in a guide by two retro-reflected laser beams in a real-time evolution. Finally, we present a phase scan of a fully guided Mach-Zehnder interferometer based on DBDs combined with Bloch oscillations for LMT.

[1] Gebbe, M., Siemß, JN., Gersemann, M. et al., Nat Comm., 12, (2021) 2544.

Q 31.7 Wed 12:30 F102

A thermal noise interferometer for the characterization of optical coatings — •Janis Wöhler[1,2], Matteo Carlassara[1,2], Firoz Khan[1,2], Philip Koch[1,2], Johannes Lehmann[1,2], Harald Lück[2,1], Juliane von Wrangel[1,2], and David S. Wu[2,1] — [1]Max Planck Institute for Gravitational Physics, Hannover — [2]Institut für Gravitationsphysik, Leibniz Universität Hannover

The peak sensitivity band of ground-based gravitational wave (GW) detectors are currently limited by a combination of quantum noise and coating thermal noise (CTN). The latter is a result of the intrinsic properties, such as the mechanical loss and Young's modulus, of the high reflective mirror coatings used in GW interferometers. We report on a 10 cm hemispherical Fabry-Perot cavity with suspended mirrors capable of directly measuring CTN on a test mirror. All other noise sources were suppressed below CTN by installing it in the 10m Prototype facility in Hannover to leverage the ultra low noise environment and laser source. The calibration of the interferometer readout was achieved with a photon calibrator. This thermal noise interferometer will be an invaluable tool for characterization as part of the current global research efforts to find suitable new coating materials for future GW detectors.

Q 31.8 Wed 12:45 F102

Analysis of polarization states in polarization maintaining optical fibers — •Johannes Bäuerlein[1,2], Jonathan Joseph Carter[1,2], and Sina Maria Koehlenbeck[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Callinstraße 38, 30167 Hannover, Germany — [2]Institut für Gravitationsphysik der Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

Optical fibers proved to be a powerful tool for several applications in the field of laser optics. Here, we contemplate the use of polarization maintaining fibers in interferometric displacement sensors as a tool to minimize the difference of the optical paths of two signals. In an interferometer, a probe and a reference signal is required. Any disturbance that is not common will couple directly into the detected signal of the interferometer. It is therefore advantageous to minimize the difference in the optical path of the signals, we achieve this by sending the signals through the same fiber. To suppress interference between the signals before it is desired, the polarization of the signals must be orthogonal. Therefore, we will study the crosstalk between the two polarization states inside the fiber and its coupling to induced phase noise. We present an optical setup that allows us to measure the strength of the noise due to the crosstalk of polarization states in a fiber. The phase fluctuations will be compared in real time before and after coupling to the fiber, and the differential measurement serves as a monitor of induced noise by the fiber.

Q 32: Members' Assembly

Time: Wednesday 13:00–14:00 Location: F342

All members of the Quantum Optics and Photonics Division are invited to participate.

Q 33: Quantum Gases: Bosons IV

Time: Wednesday 14:30–16:30 Location: A320

Q 33.1 Wed 14:30 A320

Tomography of a number-resolving detector by reconstruction of an atomic many-body quantum state — •Mareike Hetzel[1], Luca Pezzè[2], Cebrail Pür[1], Martin Quensen[2], Andreas Hüper[1,5], Jiao Geng[3,4], Jens Kruse[1,5], Luis Santos[6], Wolfgang Ertmer[1,5], Augusto Smerzi[2], and Carsten Klempt[1,5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]QSTAR and INO-CNR and LENS, Firenze, Italy — [3]Key Laboratory of 3D Micro/Nano Fabrication and Characterization of Zhejiang Province, Westlake University, Hangzhou, China — [4]Institute of Advanced Technology, Westlake Institute for Advanced Study, Hangzhou, China — [5]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), DLR-SI, Hannover, Germany — [6]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

The high-fidelity analysis of many-body quantum states of indistinguishable atoms requires the accurate counting of atoms. Here we report the tomographic reconstruction of an atom-number-resolving detector. The tomography is performed with an ultracold rubidium ensemble that is prepared in a coherent spin state by driving a Rabi coupling between the two hyperfine clock levels. The coupling is followed by counting the occupation number in one level. We characterize the fidelity of our detector and show that a negative-valued Wigner function is associated with it. Our results offer an exciting perspective for the high-fidelity reconstruction of entangled states and can be applied for a future demonstration of Heisenberg-limited atom interferometry.

Q 33.2 Wed 14:45 A320

Bose-Einstein condensation for hard-core bosons: Universal upper bound and Bogoliubov theory — •Martina Jung, Sophie Brass, Julia Liebert, Sebastian Paeckel, and Christian Schilling — Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München

Hard-core bosons (HCBs), subjected to an artificial Pauli principle with respect to the lattice site basis, are not only of broad physical relevance due to their close relation to Spin-1/2 operators, but their theoretical description has recently revealed some intriguing conceptual features: the mixed commutation relations of HCB creation and annihilation operators give rise to a universal upper bound on the number of HCBs that can condense in the maximally delocalized state.

In this talk, we explain when and how this universal bound on the maximally possible degree of condensation - given by $f = 1-\nu$, where ν is the filling factor - is saturated and dictates the physical behaviour of HCBs. In particular, we show by exact numerical means that this novel exclusion principle lies at the heart of the quantum phase transition in the one-dimensional lattice gas model. Based on this observation we then propose and work out a Bogoliubov theory specifically for HCBs in the regime of almost maximal condensation $f \approx 1 - \nu$.

Q 33.3 Wed 15:00 A320

Optimal preparation of spin squeezed states with one-dimensional Bose-Einstein Condensates — •Tiantian Zhang, Mira Maiwöger, Filippo Borselli, Yevhenii Kuriatnikov, Jörg Schmiedmayer, and Maximilian Prüfer — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien.

Rubidium Bose-Einstein Condensates (BECs) in double wells is spin squeezed in their ground state. However, direct preparation of two condensates is limited by thermal noise in the relative degree of freedom. We circumvent this on our experiment by spatially split a single one-dimensional condensate into two using radio-frequency dressing along the transverse direction of the trap with an Atom Chip. Our single-atom-sensitive fluorescence imaging system makes the sub-shot-noise detection of the number imbalance possible. We present a simple yet effective short-cut to adiabatic splitting. It exploits tunnelling dynamics in the Bosonic Josephson Junction. We have not only observed experimentally an overall enhanced number squeezing compared to direct splitting to a decoupled trap, but also directly measured the oscillation of the number squeezing. The oscillation frequencies scale with the plasma frequencies and have been measured across two orders of magnitude. We can further improve the efficiency by implementing a splitting quench. This enforces squeezing with the trap frequency which is a few times above the experimentally accessible plasma frequencies.

Q 33.4 Wed 15:15 A320

Engineering Correlated Spin-Momentum Pairs in a Quantum Gas Coupled to an Optical Cavity — Fabian Finger, Rodrigo Rosa-Medina, •Nicola Reiter, Panagiotis Christodoulou, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Quantum correlations among the constituents of many-body systems determine their fundamental properties. Quantum gases with their pristine control over external and internal degrees of freedom offer a versatile platform to manipulate and detect such correlations at a microscopic level. Here, we report on the observation of correlated atomic pairs in specific spin and momentum modes. Our implementation relies on Raman scattering between different spin levels of a spinor Bose-Einstein condensate, which is induced by the interplay of a running-wave transverse laser and the vacuum field of an optical cavity. Far-detuned from Raman resonance, a four-photon process gives rise to collectively-enhanced spin-mixing dynamics. We investigate the statistics of the produced pairs and explore their non-classical character through noise correlations in momentum space. Our results demonstrate a new platform for fast generation of correlated pairs in a quantum gas and provide prospects for matter-wave interferometry using entangled motional states.

Q 33.5 Wed 15:30 A320

Interference of two composite bosons — Mama Kabir Njoya Mforifoum, Andreas Buchleitner, and •Gabriel Dufour — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

We study the Hong-Ou-Mandel interference of two identical composite bosons, each formed of two bosonic or fermionic constituents, as they scatter against a potential barrier in a one-dimensional lattice. For tightly bound composites, we show that the combination of their constituents' mutual interactions and exchange symmetry gives rise to an effective interaction between the composites, which induces a reduction of the interference contrast.

Q 33.6 Wed 15:45 A320

A dipolar quantum gas microscope — •Ralf Klemt[1], Kevin Ng[1], Jens Hertkorn[1], Paul Uerlings[1], Akshay Shankar[2], Lucas Lavoine[1], Tim Langen[1], and Tilman Pfau[1] — [1]5. Physikalisches

Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Indian Institute of Science Education and Research, Mohali

In this talk, we present experimental and theoretical efforts towards studying dipolar Bose- and Fermi-Hubbard models using ultracold dipolar quantum gases in optical lattices. In addition to Hubbard models which only incorporate short-range interaction, the anisotropic dipolar interactions found in dysprosium, allow us to introduce (next-) nearest neighbor interactions. This opens up the possibility to explore a wide range of problems ranging from quantum magnetism and lattice spin models to topological matter. We will discuss examples of quantum phases both with local and non-local order and lay out a path towards realizing and observing them experimentally.

We will present our new setup, which is designed to combine the single-site resolution of a quantum gas microscope with the long-range and anisotropic interactions found in lanthanides. We will use fermionic and bosonic isotopes of dysprosium trapped in an UV optical lattice with a lattice spacing of 180 nm. The short lattice spacing will significantly enhance the dipolar nearest neighbor coupling to be about 200 Hz (10 nK). We will combine this setup with a single-particle, spin- and energy resolved super-resolution imaging technique, in order to be able to extract almost arbitrary density correlation functions.

Q 33.7 Wed 16:00 A320

Towards coupling atomic tweezers to an optical cavity — •Stephan Roschinski, Johannes Schabbauer, Davide Natale, Giacomo Hvaring, Iris Haubold, Nicole Heider, Alexander Heiss, Marvin Holten, and Julian Léonard — Atominstitut, TU Wien, Austria

A central goal of current research is to efficiently create entangled states among an increasing number of qubits. While atomic platforms provide great scalability, they mostly rely on local interactions, for instance, collisional or Rydberg interactions. We describe the progress to build a novel platform to entangle atoms with non-local operations using photon-mediated interactions. The atoms will be trapped within individual optical tweezers which are coupled to the field of an optical cavity. Large optical access through a high-resolution microscope objective will enable us to individually address each atom and control its coupling with all-to-all connectivity. Further advantages of this platform include partial non-destructive readout and efficient multi-qubit entanglement operations. In the long term, the proposed platform provides a scalable path to studying many-body systems with programmable connectivity, as well as an efficient atom-photon interface for quantum communication applications.

Q 33.8 Wed 16:15 A320

Floquet analysis of quantum dynamics in periodically driven optical lattices — •Usman Ali[1], Martin Holthaus[2], and Torsten Meier[1] — [1]Paderborn University, Department of Physics, Warburger Strasse 100, D-33098 Paderborn, Germany — [2]Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg, Germany

Ultracold atoms in optical lattices exhibit very rich dynamics in response to time-periodic driving. With amplitude and frequency of the driving field being the main control parameters, it is shown that the initial phase of the drive induces significantly and qualitatively different dynamics. We discuss how the role of the phase can be understood within Floquet formalism. An approach that is based on the quantum pendulum approximation, allows to analytically obtain the quasi-energy spectrum and the Floquet states. This approximation is well justified for resonant driving conditions, yet our interpretations provide a general understanding of the dynamics. We evaluate our approach for an experimentally relevant example.

Q 34: Quantum Communication (joint session QI/Q)

Time: Wednesday 14:30–16:30 Location: B305

Invited Talk Q 34.1 Wed 14:30 B305

Qube and Qube-II – Towards Quantum Key Distribution with Small Satellites — •Lukas Knips for the Qube/Qube-II-Collaboration — Ludwig Maximilian University (LMU), Schellingstr. 4, D-80799 Munich, Germany — Max Planck Institute of Quantum Optics (MPQ), Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 Munich, Germany

Quantum Key Distribution (QKD) is a provably secure method for distributing secret keys between two trusted parties over a quantum channel for symmetric cryptography. As demonstrated by the Chinese satellite MICIUS, exchange of a secure key between a satellite and an optical ground station is possible, thereby indeed enabling QKD on a global scale. While this large satellite demonstrated its feasibility, the QUBE missions are focussing on a more economic solution for global key exchange.

In this talk, I will start with an overview of the first QUBE satellite, a so-called CubeSat with a size of only $30 \times 10 \times 10\,\mathrm{cm}^3$ and consequently with severe limitations on available power and space. The satellite includes two different quantum state sources and a quantum random number generator and is now ready for launch. QUBE will test performance and space readiness of those components. QUBE-II, a second satellite, is currently being designed and will be able to exchange a key mainly thanks to a much larger optical telescope with an optical aperture of about 80 mm and to a full QKD post-processing over an optical data communication channel.

Q 34.2 Wed 15:00 B305

Security of Time-Frequency Quantum Key Distribution — •Federico Grasselli, Nikolai Wyderka, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf

One of the current drawbacks of Quantum key distribution (QKD) are the relatively low generation rates of secret keys, hindered by effects such as noise in the quantum channel and detector saturation. Such issues can be alleviated by increasing the dimension of the encoding space with time-frequency QKD, where log2(d) bits of information are encoded in 'd' time bins of a single photon, thereby increasing the efficiency of the communication.

We focus on a specific experimental implementation of time-frequency QKD that can be easily scaled to higher dimensions. For this setup, we discuss a method to prove its security by closing a critical loophole that has been often overlooked in QKD implementations based on the photons' temporal degree of freedom. Moreover, we provide preliminary experimental data demonstrating that our security method can be applied to practical time-frequency QKD setups.

Q 34.3 Wed 15:15 B305

Multipartite measurement device-independent quantum key distribution with quantum memories — •Julia Alina Kunzelmann, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf

Quantum repeaters build a useful tool to increase the communication distance in quantum networks. To achieve higher repeater rates, multiplexing between quantum memories can be used. We generalize the multiplexing scheme for quantum repeaters to N parties where the station performs GHZ measurements. This setup is used for measurement device-independent conference key agreement. In this work, we present a protocol that allows the distribution of a secret key in a multipartite star network via one central repeater station. We analyze the secret key rate of the protocol depending on various protocol parameters.

Q 34.4 Wed 15:30 B305

Easy-to-compute local Clifford invariants for graph states — •Frederik Hahn[1] and Adam Burchardt[2,3,4] — [1]Technische Universität Berlin, Berlin, Deutschland — [2]Universität Amsterdam, Amsterdam, Niederlande — [3]QuSoft, Amsterdam, Niederlande — [4]CWI, Amsterdam, Niederlande

In this work, we study easy-to-compute LC-invariants of graph states. Although previous studies have already led to finite sets of invariants that fully characterize the LC-equivalence classes of graph states, these invariants are computationally inefficient. Their computation requires knowledge of the given state's full stabilizer set, which is exponential in the number of its qubits n.

In this paper, without the need to calculate this entire stabilizer set, we instead present an easy-to-calculate LC-invariant of order O(n^3). It is closely related to the so-called foliage of a graph and has a simple graphical interpretation in terms of leaves, axils, and twins: For any graph, we define a partition of the set of its vertices based on a simple equivalence relation and call it the foliage partition of this graph. We further show that foliage partitions remain invariant under any local complementation of the corresponding graph. Foliage partitions then represent simple LC-invariants for graph states, since there is a one-to-one correspondence between LC-operations on a graph state and local complementations of its graph. Finally, we generalize foliage partitions from qubits to qudits and prove their invariance under the generalized local complementation operations.

Q 34.5 Wed 15:45 B305

Towards consumer-level quantum-secure cryptography - Entanglement based short-range Quantum Key Distribution — •Henning Mollenhauer[1], Daniel Tippel[1], Pius Gerisch[1], Donika Imeri[1,2], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg

Many schemes for Quantum Key Distribution (QKD) have been proposed and realized over the years. A common challenge that arises in experimental implementations is the exponential loss of photons in quantum channels over long distances. Solutions to this challenge like purification protocols with quantum repeaters have not to date been efficiently implemented. A different approach to QKD is the key distribution over a short distance- and therefore low-loss- quantum channel. QKD over short distances can be used to exchange an information-theoretically secure root-of-trust that is safely stored on two end modules. Based on the root-of-trust, keys for encryption are generated in re-keying schemes on each end module. With this approach, it is possible to spatially separate the end modules and communicate classically over already existing communication infrastructure. Since no quantum channel is involved in the actual process of communication, encrypted messages can be sent between end modules over arbitrary distances. We here present an experimental setup that aims to realize short-distance QKD with end modules that in the future could be made compact enough to be implemented on small silicone-based chips.

Q 34.6 Wed 16:00 B305

A theoretical and experimental analysis of the single-photon advantage in quantum coin flipping — •Fenja Drauschke[1,2], Daniel A. Vajner[1], Tobias Heindel[1], and Anna Pappa[2] — [1]Institut für Festkörperphysik, TU Berlin — [2]Institut für Softwaretechnik und Theoretische Informatik, TU Berlin

Quantum coin flipping is a prominent cryptographic primitive within the framework of non-collaborative models, where two or more distrustful parties want to perform a fair coin flip. The parties are separated by a distance and wish to agree on a random bit. Quantum coin flipping has raised much interest recently, as it has various applications and holds enormous potential for improving the security of secure communications. At the same time, the use of single-photon sources for quantum communication setups is also attracting a lot of attention as it promises further security advantages compared to the usage of weak coherent laser pulses. In this work, we investigate the advantage of using single-photon sources compared to weak coherent pulses for different quantum communication setups of coin flipping in a theoretical, as well as experimental approach.

Q 34.7 Wed 16:15 B305

Optimization and readout-noise analysis of a hot vapor EIT memory on the Cs D1 line — •Luisa Esguerra[1,2], Leon Messner[1,3], Elizabeth Robertson[1,2], Norman Vincenz Ewald[1], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany. — [3]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany.

Efficient, noise-free quantum memories are indispensable components for the realization of quantum repeaters, which will be crucial for long distance quantum communication [1, 2]. We have realized a technologically simple, in principle satellite-suited quantum memory in Cesium vapor, based on electromagnetically induced transparency (EIT) on the ground states of the Cs D1 line [3]. We focus on the simultaneous optimization of end-to-end efficiency and signal-to-noise level in the memory, and have achieved light storage at the single-photon level with end-to-end efficiencies up to 13(2)%. Simultaneously we achieve a minimal noise level corresponding to $\bar{\mu}_1 = 0.07(2)$ signal photons, for which we present strategies for further minimization. Furthermore, improvements for the next implementation of the experiment are introduced.

[1] M. Gündoğan et al., npj Quantum Information 7, 128 (2021)
[2] J. Wallnöfer et al., Commun Phys 5, 169 (2022)
[3] L. Esguerra, et al., arXiv:2203.06151 (2022)

Q 35: Quantum Optics: Cavity and Waveguide QED II

Time: Wednesday 14:30–16:30 Location: E001

Q 35.1 Wed 14:30 E001

Observation of superradiant bursts in waveguide QED — Christian Liedl, Felix Tebbenjohanns, •Constanze Bach, Sebastian Pucher, Arno Rauschenbeutel, and Philipp Schneeweiss — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Dicke superradiance describes the collective decay dynamics of a fully inverted ensemble of two-level atoms. There, the atoms emit light in the form of a short, intense burst due to a spontaneous synchronization of the atomic dipoles. Typically, to observe this phenomenon, the atoms must be placed in close vicinity of each other. In contrast, here we experimentally observe superradiant burst dynamics with a one-dimensional ensemble of atoms that extends over thousands of optical wavelengths. This is enabled by coupling the atoms to a nanophotonic waveguide, which mediates long-range dipole-dipole interactions between the emitters. The burst occurs above a threshold atom number, and its peak power scales faster with the number of atoms than in the case of standard Dicke superradiance. Moreover, we study the coherence properties of the burst and observe a sharp transition between two regimes: in the first, the phase coherence between the atoms is seeded by the excitation laser. In the second, it is seeded by vacuum fluctuations. Our results shed light on the collective radiative dynamics of spatially extended ensembles of quantum emitters and may turn out useful for generating multi-photon Fock states as a resource for quantum technologies.

Q 35.2 Wed 14:45 E001

Applications of cooperative subwavelength quantum emitter arrays — •Nico Bassler[1,2], Michael Reitz[1], Kai Phillip Schmidt[2], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University, Erlangen, Germany

Abstract: We describe applications of subwavelength quantum emitter arrays as optical elements and in the context of chiral hybrid cavity design. A single two-dimensional array can act as an optical atom-thick metasurface with a narrow reflectivity window [1]. For normal illumination, the cooperative optical response, stemming from emitter-emitter dipole exchanges, can be augmented via externally tunable magnetic fields to control the state of polarization in transmission [2]. This is particularly interesting for the case of circularly polarized light, where the array can act as a chiral mirror, thus allowing the design of strongly frequency dependent, hybrid [3], chiral cavities. We then consider the application of such chiral cavities to the sensitive detection of chirality in enantiomers.

[1] J. Rui, D. Wei, A. Rubio-Abadal, S. Hollerith, J. Zeiher, D. M. Stamper-Kurn, C. Gross, and I. Bloch, *A subradiant optical mirror formed by a single structured atomic layer,* Nature 583, 369 (2020). [2] N. S. Bassler, M. Reitz, K. P. Schmidt, C. Genes, Linear optical elements based on cooperative subwavelength emitter arrays, arXiv:2209.03204 (2022). [3] O. Cernotik, A. Dantan and C. Genes, Cavity quantum electrodynamics with frequency-dependent reflectors, Phys. Rev. Lett. 122, 243601 (2019).

Q 35.3 Wed 15:00 E001

Waveguide-coupled superconducting nanowire single-photon detectors enhanced by subwavelength grating metamaterials — •Alejandro Sánchez-Postigo, Connor Graham-Scott, and Carsten Schuck — Institute of Physics, University of Münster, Heisenbergstraße 11, 48149 Münster, Germany

Waveguide-coupled superconducting nanowire single-photon detectors (SNSPDs) have developed into one of the most attractive single-photon detector technologies for integrated quantum photonics. Embedding ultra-short, transversally oriented superconducting nanowires within optical cavities have enabled waveguide-coupled SNSPDs with ultra-fast reset times and low timing jitter. However, actual devices exhibit on-chip detection efficiencies (OCDE) as low as 30%, mainly due to scattering loss in the crossing between the waveguide and the slab that supports the nanowire.

Subwavelength grating (SWG) metamaterials are periodic structures that, patterned at a scale that is smaller than the operating wavelength, allow for synthesizing artificial materials with tailored refractive index. In the last years, SWG structures have enabled many silicon photonics devices with unprecedented performance, including waveguides, fiber-chip couplers and filters. These promising metamaterials hold great potential for engineering the integration of SNSPDs with nanophotonic waveguides and tailoring the detector performance.

Here we show our progress on integrating, for the first time, SNSPDs with SWG structures, with the aim of reducing the scattering loss of the former and hence increasing their OCDE.

Q 35.4 Wed 15:15 E001

Inverse design approach to x-ray quantum optics with Mössbauer nuclei in cavities — Oliver Diekmann[1,2], Dominik Lentrodt[1,3], and •Jörg Evers[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]Institute for Theoretical Physics, Vienna University of Technology, Austria — [3]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Nanometer-sized thin-film cavities containing ensembles of Mössbauer nuclei have been demonstrated to be a rich platform for x-ray quantum optics [1]. At low excitation, these systems allow one to implement tunable artificial quantum systems at hard x-ray energies. However, until recently, the inverse problem of determining a cavity structure which realizes a desired level scheme remained unsolved. In this talk, I will introduce the inverse design and develop a comprehensive optimization which allows one to determine optimum cavity systems realizing few-level schemes with desired properties [2,3]. Using this approach, the accessible parameter spaces of artificial multi-level systems can be characterized. Further, I will discuss a number of qualitative insights into x-ray photonic environments for nuclei that will likely impact the design of future x-ray cavities and thereby improve their performance.

[1] R. Röhlsberger and J. Evers, in: Yoshida and Langouche (eds.), Modern Mössbauer Spectroscopy, Springer Vol. 137, p. 105 (2021).
[2] O. Diekmann, D. Lentrodt and J. Evers, Phys. Rev. A 105, 013715 (2022).
[3] O. Diekmann, D. Lentrodt and J. Evers, Phys. Rev. A 106, 053701 (2022).

Q 35.5 Wed 15:30 E001

Spectral dynamics of a strongly coupled system of Yb atoms in a high-finesse cavity — Dmitriy Sholokhov, •Saran Shaju, Ke Li, and Jürgen Eschner — University of Saarland, Saarbrücken, Germany

We trap ^{174}Yb atoms in a MOT using the 182 kHz narrow $^1S_0$ - $^3P_1$ (556 nm) transition, thereby creating a considerably colder and denser atomic cloud as compared to the case of MOT trapping on the dipole-allowed, 28 MHz wide $^1S_0$ - $^1P_1$ line at 399 nm [1]. The cloud resides in a 5 cm long, ~45 000 finesse optical cavity resonant with the 556 nm transition. We observe strong nonlinear interaction between cavity and atoms which, together with the time-dependent atom number inside the cavity mode, leads to complex dynamics of the system. In this contribution we characterize and analyze time-dependent and spectral properties of the light emitted into cavity and free space.

[1] H. Gothe, D. Sholokhov, A. Breunig, M. Steinel, J. Eschner, Phys. Rev. A 99, 013415 (2019)

Q 35.6 Wed 15:45 E001

Controlling the spontaneous emission of trapped ions for quantum applications — •Giovanni Cerchiari, Yannick Weiser, Lorenz Panzl, and Rainer Blatt — Universität Innsbruck, Technikerstrasse 25/4, A-6020 Innsbruck, Austria

Trapped atomic ions are one of the most prominent platforms for bridging the gap between fundamental quantum physics research and quantum technology applications. In ions, laser excitation is used to encode quantum information into the electronic excited states, which, however, are unstable and can spontaneously relax by photon emission. The spontaneous emission of photon is recognized as one of the key constraints for the long-term storage of information and for the encoding process. In this contribution, I will explain why we believe that spontaneous emission is not a fundamental limit, but rather a phenomenon that may be controlled and suppressed to enhance quantum technology.

Q 35.7 Wed 16:00 E001

Subradiant States in Cavity QED — •Tom Schmit[1], Alexander Baumgärtner[2], Simon Hertlein[2], Carlos Máximo[2], Davide Dreon[2], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

We analyse theoretically self-organization of transversally pumped atoms that strongly couple to two cavity modes in the dispersive regime by means of the quantum master equation of Ref. [1]. We determine the stationary state and discuss the emerging phase diagram as a function of the experimental control parameters. We argue that, when the atomic detuning from the pump is on the blue, the atoms selforganize in patterns that exhibit the characteristics of subradiance. We then analyse the stability of these subradiant states by means of a quantum Euler equation, which we derive from the master equation in an appropriate limit. We compare our predictions with experimental measurements in the corresponding regime and find qualitative and quantitative agreement. ~\\ \$[1]\$ S. B. J{\"a}ger, T. Schmit, G. Morigi, M. J. Holland, and R. Betzholz, Phys. Rev. Lett. \textbf{129}, 063601 (2022).\\ \$[2]\$ P. Zupancic, D. Dreon, X. Li, A. Baumgärtner, A. Morals, W. Zheng, N. R. Cooper, T. Esslinger, and T. Donner, Phys. Rev. Lett. \textbf{123}, 233601 (2019).

Q 35.8 Wed 16:15 E001

Waveguide QED with Rydberg superatoms — •Nina Stiesdal[1], Lukas Ahlheit[1], Kevin Kleinbeck[2], Jan Kumlin[3], Anna Spier[1], Jan de Haan[1], Hans-Peter Büchler[2], and Sebastian Hofferberth[1] — [1]IAP, University of Bonn — [2]ITP3, University of Stuttgart — [3]CCQ, Aarhus University

The field of Waveguide QED investigates how light in a single mode propagates through a system of localized quantum emitters. If the coupling between individual photons and emitters is sufficiently strong, the photons can mediate an effective interaction between the emitters, creating a many-body system. The cascaded interaction with saturated emitters can be interpreted as a photon-photon interaction.

We realize effective two-level emitters by exploiting the Rydberg blockade effect. By confining N~10.000 atoms to a single blockaded volume, the ensemble only supports a single excitation creating a so-called Rydberg superatom. Due to the collective nature of the excitation, the superatom effectively represents a single emitter coupling strongly to single photons. The directional emission of the superatom into the initial probe mode realizes a waveguide-like system in free-space without any actual light-guiding elements.

This talk will discuss how we scale this system from one to few strongly coupled superatoms to study how the propagation of quantized light fields through a small emitter chain results in photon-photon correlations and entanglement between the emitters. We also show how we use controlled dephasing of the collective excitation into collective dark states to subtract exact photon numbers from an incoming pulse.

Q 36: Quantum Technologies (joint session Q/MO/QI)

Time: Wednesday 14:30–16:30 Location: E214

Invited Talk Q 36.1 Wed 14:30 E214

BMBF-Förderprogramm: Wissenschaftliche Vorprojekte — •Bernhard Ihrig und Johannes Mund — VDI Technologiezentrum GmbH

Die zweite Quantenrevolution und die schnell voranschreitenden Entwicklungen in der Photonik bieten großes Potenzial für Anwendungen in Ökonomie, Ökologie und Gesellschaft. Zugleich sind neue Erkenntnisse aus der Grundlagenforschung in einem frühen Stadium hinsichtlich der Herausforderungen und Risiken bei der Umsetzung oftmals kaum zu beurteilen. Daher müssen wissenschaftlich-technische Vorarbeiten eine Grundlage schaffen, die es ermöglicht, das Potenzial einer neuen Erfindung bzw. der neuen wissenschaftlichen Erkenntnis zu bewerten.

Das Bundesministerium für Bildung und Forschung (BMBF) beabsichtigt daher, sogenannte Wissenschaftliche Vorprojekte (WiVoPro) im Bereich der Photonik und der Quantentechnologien auf Grundlage des Forschungsprogramms Quantensysteme zu fördern. Das Ziel dieser Vorprojekte besteht darin, wissenschaftliche Fragestellungen im Hinblick auf zukünftige industrielle Anwendungen in den Quantentechnologien und der Photonik zu untersuchen. Sie sollen die bestehende Forschungsförderung ergänzen und eine Brücke zwischen Grundlagenforschung und industriegeführter Verbundförderung schlagen.

Wir als Projektträger VDI Technologiezentrum GmbH möchten die Maßnahme in diesem Rahmen vorstellen, bewerben und Ihre Fragen für eine mögliche Förderung beantworten.

Q 36.2 Wed 15:00 E214

Mikrofabrikation von Ionenfallen für einen skalierbaren Quantencomputer — •Eike Iseke[1,2], Friederike Giebel[1,2], Nila Krishnakumar[1,2], Konstantin Thronberens[1,2], Jacob Stupp[1,2], Amado Bautista-Salvador[1,2] und Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Hannover, Deutschlad — [2]Physikalisch Technische Bundesanstalt, Braunschweig, Deutschland

Die Ionenfallentechnologie ist eine vielversprechende Option auf dem Weg zur Entwicklung eines skalierbaren Quantencomputers. Eine mögliche Realisierung stellt die Multilagen-Ionenfalle dar [1]. Durch multiple Lagen wird die Integrationsdichte entscheidend erhöht und es können neuartige Ionenfallendesigns realisiert werden.

Die zunehmende Komplexität der Fallen stellt neue Anforderungen an die Mikrofabrikationsmethoden. Forschung und Entwicklung in diesem Feld fokussieren sich unter anderem auf die Interposer-Technologie, das Thermokompressionsbonden und die Substratdurchkontaktierung mittels TSVs (through silicon vias).

Diese fortschrittlichen Fabrikationsmethoden ermöglichen die Skalierung der Plattform sowohl durch die Möglichkeit die Anzahl der geführten Signale zu erhöhen, als auch durch die gesteigerte Zuverlässigkeit der Verbindungstechnologie.

Q 36.3 Wed 15:15 E214

Squeezed States of Light for Future Gravitational Wave Detectors at a Wavelength of 1550 nm — •Fabian Meylahn[1,2], Benno Willke[1,2], and Henning Vahlbruch[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany — [2]Leibniz Universität Hannover, D-30167 Hannover, Germany

The generation of strongly squeezed vacuum states of light is a key technology for future ground-based gravitational wave detectors (GWDs) to reach sensitivities beyond their quantum noise limit. For some proposed observatory designs, an operating laser wavelength of 1550 nm or around 2 μm is required to enable the use of cryogenically cooled silicon test masses for thermal noise reduction. Here, we present the first the direct measurement of up to 11.5 dB squeezing at 1550 nm over the complete detection bandwidth of future ground-based GWDs ranging from 10 kHz down to below 1 Hz. Furthermore, we directly observe a quantum shot-noise reduction of up to 13.5 dB at megahertz frequencies. This allows us to derive a precise constraint on the absolute quantum efficiency of the photodiode used for balanced homodyne detection. These results hold important insight regarding the quantum noise reduction efficiency in future GWDs, as well as for quantum information and cryptography, where low decoherence of nonclassical states of light is also of high relevance.

Q 36.4 Wed 15:30 E214

A single-photon source based on hot Rydberg atoms — •Jan Reuter[1,2], Max Mäusezahl[3], Felix Moumtsilis[3], Tilman Pfau[3], Tommaso Calarco[1,2], Robert Löw[3], and Matthias Müller[1] — [1]Forschungszentrum Jülich GmbH — [2]Universität zu Köln — [3]Universität Stuttgart

The leading effects of a single-photon source based on Rydberg atoms are the strong van-der-Waals interaction between the atoms as well as the collective decay of the atom ensemble. Our setup is a vapor cell filled with Rubidium atoms which we excite via three different laser pulses. The decay of this excitation will then lead to the emission of a single photon. To ensure robustness, we investigated the behavior of moving Rydberg atoms and optimized the laser pulse sequence. For that, we simulated the transitions of Rubidium atoms from the ground state over the Rydberg state up to the singly-excited collective states. We can show that the collective decay of the single excitations leads to a fast and directed photon emission, while double excitations show no or only weak collective properties.

Q 36.5 Wed 15:45 E214

Resolving photon numbers using ultra-high-resolution timing single-channel electronic readout of a conventional superconducting nanowire single photon detector — •Gregor Sauer[1,2], Mirco Kolarczik[3], Rodrigo Gomez[1,2], Helmut Fedder[3], and Fabian Steinlechner[1,2] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, 07743 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [3]Swabian Instruments GmbH, 70435 Stuttgart, Germany

Photon-number-resolving (PNR) detectors are indispensable building blocks for applications in quantum communications, computing, and sensing. PNR is commonly achieved by multiplexing onto several superconducting nanowire single-photon detectors (SNSPD) or using transition-edge sensors with energy- and photon-number resolution. This comes at the cost of resource overhead (for multiplexing) or long recovery times (for transition-edge sensors).

Here, we show how ultra-high-resolution timing measurements of the rising and falling edge of electrical pulses generated from the SNSPDs enable to distinguish photon numbers of up to 5 in a single-shot measurement. This provides a practical and comparably low-cost PNR detector, offering high detection efficiency and operational repetition rate. We present the implementation of such a PNR detector system (in the telecom C-band) and its characterization by measuring the photon-number statistics of a 300fs-pulsed coherent input source with tunable average photon number and repetition rate.

Q 36.6 Wed 16:00 E214

N00N-states for super-resolving quantum imaging and sensing — •Gil Zimmermann[1] and Fabian Steinlechner[1,2] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, 07743 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany

Quantum measurement techniques can serve to improve precision imaging and sensing through entanglement. Employing N00N-states, i.e., maximally path-entangled photon-number states of two modes, the Heisenberg limit 1/N with N photons can be reached in precision phase measurements, thus overcoming the shot-noise limit. Furthermore, the Rayleigh diffraction limit can be overcome by a factor N. Therefore, the goal is to efficiently generate high N00N-states with N>2 to improve current sensing schemes achieving super-resolution and super-sensitivity. High-N00N states with N=5 photons have already been generated experimentally with high fidelity, as shown by Afek et al. This talk will focus on schemes with relatively low complexity to generate high N00N-states. In addition, applications of high-N00N states, e.g., in the context of quantum-enhanced lidar systems or quantum microscopy, are discussed, taking into account their high fragility due to interactions with the environment.

Q 36.7 Wed 16:15 E214

Non-destructive measurement of phonon number states using the Autler-Townes effect — •Marion Mallweger[1], Murilo de Oliveira[2], Robin Thomm[1], Harry Parke[1], Natalia Kuk[1], Ger-

ard Higgins[1,3], Romain Bachelard[2,4], Celso Villas-Boas[2], and Markus Hennrich[1] — [1]Department of Physics, Stockholm University, Sweden — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil — [3]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Sweden — [4]Université Côte d'Azur, CNRS, Institut de Physique de Nice, France

Quantum technologies employing trapped ion qubits are currently some of the most advanced systems with regards to experimental methods in quantum computation, simulation and metrology. This is primarily due to the excellent control available over the ions' motional and electronic states. In this work we present a new method to measure the distribution of motional number states in a non-destructive manner. The technique can be applied to all platforms where a quantum harmonic oscillator is coupled to a three level system. We demonstrate the technique using a single trapped $^{88}Sr^+$ ion. The method relies on the Autler-Townes effect that arises when two levels are strongly coupled while being probed by a third level. If the two levels are coupled on a sideband transition, then the magnitude of the Autler-Townes splitting depends on the phonon number state. This new method provides a robust and efficient way of measuring motional states of quantum harmonic oscillators. It can even be applied to perform single shot measurements of phonon number states in a non-destructive way.

Q 37: Collisions (with Q) (joint session MO/Q)

Time: Wednesday 14:30–16:15 Location: F142

Q 37.1 Wed 14:30 F142

Gas phase investigations on dynamics of the reaction of tantalum cation Ta^+ with carbon dioxide CO_2 — •Marcel Meta[1], Maximilian Huber[1], Maurice Birk[1], Atilay Ayasli[2], Tim Michaelsen[2], Roland Wester[2], and Jennifer Meyer[1] — [1]RPTU Kaiserslautern-Landau, Fachbereich Chemie, Kaiserslautern, Germany — [2]Universität Innsbruck, Institut für Ionenphysik und Angewandte Physik, Innsbruck, Austria

The dynamics of the *oxygen atom transfer* (OAT) reaction $Ta^+ + CO_2 \rightarrow TaO^+ + CO$ in gas phase could be investigated under single collision conditions. The measured energy and angle differential cross sections allow us to probe the rearrangement of atoms during reaction, i.e. the atomistic dynamics [1]. The preset results were measured with our new 3D velocity map imaging setup in Kaiserslautern. The reaction is exothermic and spin forbidden in the ground state but takes place due to an efficient crossing from the quintet surface over to the triplet surface. Hence, it was found that the reaction almost proceeds with collision rate at room temperature [2-4]. The TaO^+ velocity map images shows dominant indirect dynamics even at high collision energies with most of the additional collision energy partitioned into internal excitation.

[1] J. Meyer, R. Wester, Annu. Rev. Phys. Chem. 2017, 68, 333; [2] R. Wesendrup, H. Schwarz, Angew. Chem. Int. Ed. 1995, 34, 2033; [3] G. K. Koyanagi, D. K. Bohme, J. Phys. Chem. A 2006, 110, 1232; [4] N. Levin, J. T. Margraf, J. Lengyel, K. Reuter, M. Tschurl, U. Heiz, Phys. Chem. Chem. Phys. 2022, 24, 2623

Q 37.2 Wed 14:45 F142

Dissociative recombination of ArH^+ at the Cryogenic Storage Ring — •Ábel Kálosi[1,2], Manfred Grieser[2], Leonard W. Isberner[3,2], Daniel Paul[1,2], Daniel W. Savin[1], Stefan Schippers[3], Viviane C. Schmidt[2], Andreas Wolf[2], and Oldřich Novotný[2] — [1]Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [3]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Gießen, Germany

ArH^+ is an important probe of the cosmic ray flux in interstellar space. Cosmic rays are the dominant ionization source for H and H_2 in the cold interstellar medium (ISM). This ionization initiates astrochemistry in the cold phases of the ISM. The cosmic ray ionization rate (CRIR) is thus an important parameter for both chemical and dynamical models of the ISM. ArH^+ forms via cosmic ray ionization of Ar, but can be destroyed via dissociative recombination (DR) with free electrons. Astronomical observations of ArH^+, combined with chemical models, enable one to quantitatively estimate the CRIR. Such models require reliable rate coefficients that take into account the low internal excitation of the ArH^+, as occurs in the cold ISM. To this end, we have performed merged-beams DR experiments with ArH^+ in the Cryogenic Storage Ring where, at an ambient temperature of ~ 10 K, the ions relaxed to their lowest rotational states.

Q 37.3 Wed 15:00 F142

Laser induced forced evaporative cooling of molecular anions — •Eric Endres[1], Jonas Tauch[2], Saba Hassan[2], Markus Nötzold[1], Roland Wester[1], and Matthias Weidemüller[2] — [1]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria — [2]Physikalisches Institut, Universität Heidelberg, Germany

Cooling molecular anions is key for the production of cold antihydrogen and the creation of anionic coulomb crystals and would open up new fundamental research areas in modern physics and chemistry. An established technique to store and cool anions are collisions with buffer gas in multipole radio frequency ion traps. However, the temperature is limited by the temperature of the used cryogenic cooling medium.

In this contribution we present forced evaporative cooling down to 2.2(8) K by means of photodetachment of an anionic OH^- ensemble, confined in a multipole wire trap. [1] This enables a phase space density approaching the near-strong Coulomb coupling regime. The anion cooling dynamics are described by a quantitative analysis of the experimental results with a full thermodynamic model [2] without any fitting parameters. In principle, this technique can be used for cooling basically any anionic species below the temperature of liquid helium.

[1] J. Tauch, et al. arXiv preprint arXiv:2211.11264 (2022).
[2] A. Crubellier. J. Phys. B, 23(20), 3585 (1990).

Q 37.4 Wed 15:15 F142

Product spin and binding energy propensities for three-body recombination of ultracold atoms — •Jinglun Li[1], Shinsuke Haze[1], José P. D'Incao[1,2], Dominik Dorer[1], Markus Deiss[1], Eberhard Tiemann[3], Paul S. Julienne[4], and Johannes Hecker Denschlag[1] — [1]Institut für Quantenmaterie, Universität Ulm, Germany — [2]JILA, University of Colorado, USA — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [4]JQI, University of Maryland, USA

Three-body recombination (TBR) is an elementary chemical reaction process, in which free atoms collide to form a molecule and release the binding energy E_b into the translational movement of the molecule and the third atom. Knowing favored molecular products in TBR is crucial for various fields such as astrophysics, atmospheric physics, and physical chemistry. In recent years we have been working experimentally and theoretically on TBR of ultracold atoms and have achieved great progress in identifying the molecular product distribution on a full quantum state resolution level. In particular, for ultracold Rb atoms we find that TBR intends to produce a molecule preserving the initial spins of two atoms that form it and that the state-to-state reaction rate follows roughly a power-law scaling $L_3 \propto 1/E_b$. Our numerical simulations predict that the $1/E_b$ propensity even holds, with a different prefactor, for two specific groups of molecular products disfavored by the spin propensity. We further elaborate a more comprehensive theoretical investigation on different alkali-metal species to explore the modifications and breakdowns of these propensities.

Q 37.5 Wed 15:30 F142

Two-photon optical shielding of collisions between ultracold polar molecules. — •Charbel Karam[1], Mara Meyer zum Alten Borgloh[3], Romain Vexiau[1], Maxence Lepers[2], Silke Ospelkaus[3], Nadia Bouloufa-Maafa[1], Leon Karpa[3], and Olivier Dulieu[1] — [1]Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton, Orsay 91400, France — [2]Laboratoire interdisciplinaire Carnot de Bourgogne, Cedex F-21075 Dijon, France — [3]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

We propose a method to engineer repulsive long-range interactions between ultracold ground-state molecules using optical fields, thus preventing short-range collisional losses. It maps the microwave coupling recently used for collisional shielding onto a two-photon transition, and takes advantage of optical control techniques. In contrast to one-photon optical shielding [Phys. Rev. Lett. 125, 153202 (2020)], this scheme avoids heating of the molecular gas due to photon scattering. The proposed protocol, exemplified for 23Na39K, should be applicable to a large class of polar diatomic molecules.

Q 37.6 Wed 15:45 F142

Light controlled engineering of long-range molecular states — •Patrick Mischke, Jana Bender, Tanita Klas, Florian Binoth, Thomas Niederprüm, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

We experimentally engineer the deformation of the 5S-6P potential of Rubidium atoms at large interatomic distances on the order of several hundred Bohr radii. This deformation leads to a potential shape that supports bound molecular states.

To achieve this, we couple off-resonantly to an ultra-long range Rydberg molecule potential using strong laser driving. Properties that are commonly associated with Rydberg molecules, usually formed by an Rydberg atom and a ground state atom, are optically admixed to the 5S-6P pair state.

We spectroscopically observe the photoassociated 5S-6P molecules. The change in binding energy for different experimental coupling parameters is in qualitative agreement with a simple theoretical model.

Q 37.7 Wed 16:00 F142

Electric-field-controlled dipolar collisions between trapped polyatomic molecules — •Florian Jung, Manuel Koller, Jindaratsamee Phrompao, Martin Zeppenfeld, Isabel M. Rabey, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Polar symmetric top molecules exhibit a permanent electric dipole moment which creates strong anisotropic interactions, and allows them to be manipulated with moderate electric fields. This, together with their multitude of internal states, renders them promising for applications in e.g. quantum information processing or cold chemistry. For these applications reaching high-density low-temperature ensembles is imperative. This requires the capability to control collisional losses, which is a challenging task.

By combining a cryogenic buffer-gas cell with a centrifuge decelerator and an electrostatic trap, we can now confine up to 2×10^7 CH_3F molecules at a temperature of ~ 350 mK for several seconds, achieving densities of up to $10^7/\mathrm{cm}^3$, which allows for the observation of collisions [1]. We employ a homogeneous control field, covering a large fraction of our trap to mitigate collisional losses and obtain inelastic loss coefficients below $4 \times 10^{-8}\mathrm{cm}^3/\mathrm{s}$. An ab-initio theory shows excellent agreement with our experiment and highlights dipolar relaxation as the major loss mechanism. These findings are immediately relevant for cold molecular collision studies and an important step towards the observation of re-thermalisation between polyatomic molecules.

[1] M. Koller *et al.*, Phys. Rev. Lett. **128**, 203401 (2022).

Q 38: Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)

Time: Wednesday 14:30–16:30 Location: F303

Q 38.1 Wed 14:30 F303

Topological phases of Rydberg spin excitations in a honeycomb lattice induced by density-dependent Peierls phases — •Simon Ohler[1], Maximilian Kiefer-Emmanouilidis[1,2], and Michael Fleischhauer[1] — [1]University of Kaiserslautern-Landau, D-67663 Kaiserslautern, Germany — [2]German Research Centre for Artificial Intelligence, D-67663 Kaiserslautern, Germany

We show that the nonlinear transport of bosonic excitations in a honeycomb lattice of spin-orbit coupled Rydberg atoms gives rise to disordered quantum phases which are topological and candidates for spin liquids. As demonstrated in [Lienhard *et al.* Phys. Rev. X, **10**, 021031 (2020)] the spin-orbit coupling breaks time-reversal and chiral symmetries and leads to a density-dependent complex hopping of the hard-core bosons or equivalently to complex XY spin interactions. Using exact diagonalization (ED) we investigate the phase diagram resulting from the competition between density-dependent and direct transport. In mean-field there is a transition from a quasi-condensate to a 120°-phase when the complex hopping exceeds the direct one. In the full model a new phase with a finite spin gap emerges close to the mean-field critical point due to quantum fluctuations induced by the density-dependence of the hopping. We show that this phase is a genuine disordered one. It has a large spin chirality and a many-body Chern number $C = 1$, which is robust to disorder. ED simulations of small lattices point to a non-degenerate ground state and thus to a bosonic integer-quantum Hall (BIQH) phase, protected by $U(1)$ symmetry.

Q 38.2 Wed 14:45 F303

Self-Organized Criticality and Griffith's Effects — •Daniel Brady and Michael Fleischhauer — University of Kaiserslautern - Landau, Kaiserslautern, Germany

Rydberg atoms interact strongly over very large distances leading to effects such as blockade and facilitation. Using Monte-Carlo simulations of an optically driven Rydberg many body gas in the facilitation regime, we analyse the effects of disorder on the facilitation dynamics of the system. In the absence of disorder, realised e.g. by the thermal motion of the atoms, the system exhibits a phase transition between an active and an absorbing phase. The presence of an additional slow decay results in self-organized criticality.

In the low temperature limit, dynamics in the gas are entirely determined on a local scale giving rise to a heterogeneous, disordered Griffiths phase. Here, the facilitation dynamics are constrained to clusters where inter-atom distances equal the facilitation distance. The structure of these clusters can be mapped to an Erdos-Renyi graph. We numerically investigate the dynamics and improve an existing Langevin equation to this regime.

Furthermore, since the network structure changes slower than the internal facilitation dynamics in this regime, spatial correlations appear between atoms. We investigate these utilizing a two atom toy model.

Q 38.3 Wed 15:00 F303

Deexcitation of Rydberg atoms in the neutrino mass experiment KATRIN using THz radiation* — •Shivani Ramachandran — Bergische Universität Wuppertal (BUW)

The key requirement for the KArlsruhe TRItium Neutrino experiment (KATRIN) in measuring the effective electron anti-neutrino mass with a sensitivity of 200 meV at 90% (C.L.)is, minimal background. In order to achieve that and eliminate some known contributors, several background suppression methods have already been implemented. Presently the most prominent contribution to the background in the measured signal is electrons produced by the thermal ionization of Rydberg atoms. They originate due to the sputtering of ^{210}Pb from inherent radioactivity from the walls of the KATRIN main spectrometer. A plausible method is using THz and microwave radiation (method developed by ASACUSA CERN) which can lead to a reduced lifetime of Rydberg atoms and allow for dedicated stimulated de-excitation. The influence of THz light source in the main spectrometer along with the state and spatial evolution of the Rydberg atoms is presented via simulations. Different species of atoms are sputtered which can lead to two-electron excited states, ultralong-range Rydberg atoms, etc, such possibilities are discussed. The influence of magnetic fields on the emission of ionization electrons is also investigated to understand the background model better.

*Gefördert durch die BMBF-Verbundforschung Astroteilchenphysik

Q 38.4 Wed 15:15 F303

A linear response protocol to probe aging in a disordered Rydberg quantum spin system — •Moritz Hornung, Eduard Braun, Dillen Lee, Titus Franz, Sebastian Geier, Gerhard Zürn, and Matthias Weidemüller — Physikalisches Institut, Heidelberg University, Germany

In spite of many years of research, the question of whether or not the spin glass transition in disordered Heisenberg spin systems is a true phase transition is still open for debate. Of late, emerging platforms for quantum simulation greatly increase the accessibility of these systems and thus provide further insight into the topic. Already, anomalously slow dynamics that are characteristic for spin glasses have been observed on a platform consisting of Rydberg atoms, where the spin degree of freedom is encoded within highly excited electronic states.

To extend on these findings, we propose an experimental sequence based on slow ramps of the external field. This allows for the initialization of low energy states, which correspond to the low effective temperatures needed in order to observe a spin glass transition. We then introduce a small perturbation of the external field to measure the linear response depending on the speed of the initialization ramp. Finally, the platform is used to probe whether aging, rejuvenation and memory effects as observed in open spin glasses exist in a similar fashion for isolated quantum spin systems. The experimental results are complemented with numerical simulations based on exact diagonalization of a small system.

Q 38.5 Wed 15:30 F303

Analysing crosstalk with the digital twin of a Rydberg atom QPU — •Alice Pagano[1,2,3], Daniel Jaschke[1,2,3], Sebastian Weber[4], and Simone Montangero[1,2,3] — [1]Institute for Complex Quantum Systems, Ulm University — [2]Dipartimento di Fisica e Astronomia "G. Galilei" & Padua Quantum Technologies Research Center, Università degli Studi di Padova — [3]INFN, Sezione di Padova — [4]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, Stuttgart University

Decoherence and crosstalk are two adversaries when aiming to parallelize a quantum algorithm: on the one hand, the execution of gates in parallel reduces decoherence due to a shorter runtime, but on the other hand, parallel gates in close proximity are vulnerable to crosstalk. This challenge is visible in Rydberg atom quantum computers where atoms experience strong van der Waals interactions decaying with distance. We demonstrate how the preparation of a 64-qubit GHZ state is affected by crosstalk in the closed system with the help of a tensor network digital twin of a Rydberg atom QPU. Then, we compare the error from crosstalk to the decoherence effects proving the necessity to parallelize algorithms.

Q 38.6 Wed 15:45 F303

Probing the presence of phase transitions in disordered quantum spin systems — •Eduard Jürgen Braun, Moritz Hornung, Titus Franz, Dillen Lee, Sebastian Geier, Gerhard Zürn, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Closed many-body quantum systems out of equilibrium can show interesting behaviour without classical counterpart, where many-body localization and discrete time crystals are among the most prominent examples. Some theories also predict a spin-glass to paramagnet quantum phase transition within a many-body localized phase. Inspired by these predictions, in this talk we are going to present our latest results to probe a possible quantum phase transition in a disordered spin system.

To experimentally study the existence of a phase transition we will use our quantum simulation platform based on a frozen Rydberg gas in order to probe nonequilibrium properties of Heisenberg XXZ spin models. By choice of an appropriate combination of Rydberg states, different symmetry classes, like the Heisenberg XX, XXZ and Ising models can be realized. For these interacting systems, we have found glassy dynamics and a non-thermalizing regime hinting towards the presence of a localized phase.

Q 38.7 Wed 16:00 F303

Spatially and temporally resolved wavepacket dynamics of an ion-Rydberg system by means of a high-resolution ion microscope — •Herrera-Sancho OA, Berngruber Moritz, Anasuri Viraatt SV, Conrad R, Yi-Quan Zou, Zuber Nicolas, Meinert Florian, Löw Robert, and Pfau Tilman — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, Germany

The superb control along with the manipulation of ultracold temperature species have permitted access to explore interactions in ensembles of neutral atoms. When these complex systems are excited to Rydberg states, and are very close, consequently induces a blockade effect. The latter has opened the door in order to address many questions and give rise to explore, for example, trimers with multiple correlated systems, ultracold ionic impurities, individual ion-atom collisions and to probe quantum macroscopicity. In this direction, we focus on the direct spatially and temporally resolved S-state wavepacket dynamics of an ion-Rydberg system using our advanced high-resolution ion microscope. By employing a single cold Rb+ ion which facilitates the excitation of a Rydberg atom over thirty micrometers distances, the experimental findings provide evidence to indicate the shape of the wavepacket dynamics in the polarization C4 potential of the ion-Rydberg interaction. These results are compared with the theoretical predictions where it is examined the effect of the adiabatic transition from the S-states with no bound states into the steep section corresponding to non-adiabatic of the high-l states.

Q 38.8 Wed 16:15 F303

Chiral Rydberg States of Laser Cooled Atoms — •Stefan Aull[1], Steffen Giesen[2], Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Experimentalphysik 1, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel — [2]Fb. 15 - Chemie, Hans-Meerwein-Straße 4, 35032 Marburg — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

We propose a protocol for the preparation of chiral Rydberg states. It has been shown theoretically that using a suitable superposition of hydrogen wavefunctions, it is possible to construct an electron density and probability current distribution that has chiral nature [1]. Following a well established procedure for circular Rydberg state generation and subsequent manipulation with taylored radio frequency pulses under the influence of electric and magnetic fields, the necessary superposition of hydrogen-like states with correspondingly adjusted phases can be prepared. Enantio-sensitive detection using photo-ionization with circularly polarized light is under theoretical and experimental development. The results are aimed to be used for chiral discrimination [2] of molecules.

[1] A. F. Ordonez and O. Smirnova, Propensity rules in photoelectron circular dichroism in chiral molecules. I. Chiral hydrogen, Phys. Rev. A, vol. 99, no. 4, p. 43416

[2] S. Y. Buhmann et al., Quantum sensing protocol for motionally chiral Rydberg atoms, New Journal of Physics, vol. 23, no. 8, Art. no. 8, Aug. 2021

Q 39: Quantum Optics & Nano-Optics

Time: Wednesday 14:30–16:30 Location: F342

Q 39.1 Wed 14:30 F342

Ultra-small superconducting Nb-based plasmonic perfect absorbers single mode fiber coupled photodetectors — •Philipp Karl[1], Sandra Mennle[1], Monika Ubl[1], Ksenia Weber[1], Pavel Ruchka[1], Mario Hentschel[1], Philipp Flad[1], Jing-Wei Yang[2,3], Tzu-Yu Peng[2,3], Yu-Jung Lu[2,3], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Research Center for Applied Sciences, Academia Sinica, Taipei 11529, Taiwan — [3]Department of Physics, National Taiwan University, Taipei 10617, Taiwan

Quantum technologies require high-quality and efficient photodetectors and the ability to detect single photons, which can be provided by superconducting nanowire single photon detectors.

In this work, we present a superconducting niobium-based plasmonic perfect absorber detector and utilize the tunable plasmonic resonance to create a photodetector with near-100% absorption efficiency in the near-infrared spectral range. To reach the near-100% absorption, we take advantage of resonant plasmonic perfect absorber effects. This leads to an angle insensitivity and a high resonant absorption cross-section, which enable ultra-small active areas and short recovery times.

The ultra-small active areas are aided by a directly coupled single mode fiber in combination with high NA micro optics, which are printed onto the fiber.

Q 39.2 Wed 14:45 F342

Frequency Conversion in pressurized Hydrogen — •Alireza

Aghababaei — Nussallee 12, 53115 Bonn, Deutschland

State-preserving frequency conversion in the optical domain is a necessary component in many configurations of quantum information processing and communication. Thus far, nonlinear crystals are used for this purpose. Here, we report on a new approach based on coherent anti-Stokes Raman scattering (CARS) in dense molecular hydrogen gas. This four-wave mixing process sidesteps the limitations imposed by crystal properties, it is intrinsically broadband and does not generate an undesired background. We demonstrate this method by converting photons from 434 nm to 370 nm and show that their polarization is preserved.

Q 39.3 Wed 15:00 F342

Low-noise quantum frequency conversion of single photons from silicon-vacancy centers in diamond to the telecom C-band — •Marlon Schäfer, Benjamin Kambs, Tobias Bauer, Dennis Herrmann, David Lindler, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

The vast majority of systems suitable as a quantum emitter for quantum communications show optical transitions in the visible or near infrared spectral region. Therefore, quantum frequency conversion (QFC) into low-loss telecom bands is the key enabling technology for long-range fiber-based quantum networks. Here, in addition to achieving high conversion efficiencies, the key issue is to minimize the conversion-induced noise photons in the target band. Especially conversion schemes that require a mixing wavelength in the vicinity of the target wavelength lead to high noise counts. A promising quantum emitter affected by this is the silicon-vacancy (SiV) center in diamond, where direct conversion to 1550 nm implies a mixing wavelength at 1405 nm, thus resulting in strong Raman and SPDC noise.

We present an efficient and low-noise QFC device converting SiV photons into telecom C-band. In a two-stage conversion process, the photons are first converted to an intermediate wavelength and then transduced to the target wavelength. This greatly increases the spectral distance between the mixing and the target wavelength, leading to very low noise rates of less than 1 photon/s/GHz. We discuss current limitations and applicability to other platforms such as SnV centers.

Q 39.4 Wed 15:15 F342

Towards interfacing a multiplexed warm vapor quantum memory with single photons from cavity enhanced spontaneous parametric down-conversion — •Leon Messner[1,2], Elizabeth Robertson[2,3], Luisa Esguerra[2,3], Helen Chrzanowski[2], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Berlin, Germany — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany

Recent investigation [1] shows that a significant speed-up in intercontinental quantum key distribution is achievable by having quantum memories with on the order of 10^3 randomly accessible storage modes. We present our latest results on a spatially multiplexed warm vapor EIT memory [2] with the ability to scale beyond this number, while having modest technological requirements. In future, this will allow isolated deployment away from laboratory infrastructure and facilitate remote operation on satellites and similarly insular locations. To gain a deeper understanding of the challenges presented by integrating these memories into quantum networks, we are planning to interface them with single photons generated by spontaneous parametric down-conversion inside a monolithic cavity [3,4].

[1] Wallnöfer, J. et al., Commun Phys **5**, 169 (2022)
[2] Esguerra, L. et al., arXiv:2203.06151 **[quant-ph]** (2022)
[3] Mottola, R. et al., Optics Express **28**, 3159-3170 (2020)
[4] Buser, G. et al., PRX Quantum **3**, 020349 (2022)

Q 39.5 Wed 15:30 F342

Two-Step Frequency Conversion from 637nm to telecom wavelengths in a PPLN waveguide — •Joscha Hanel — AG Nanooptik, Humboldt-Universität zu Berlin — AG Ding, ATMOS, Leibniz Universität Hannover

In the future, the reliable on-demand generation of single photons at telecommunication wavelengths will be an essential tool in mid- to long-range quantum communication networks. However, many known single photon sources operate at wavelengths in the visible or near-infrared, where transmission in telecommunication fibers is far from optimal. A promising technology to bridge this wavelength gap is quantum frequency conversion. In this talk, a novel device is presented that was designed to convert light from 637nm to telecommunication wavelengths using difference frequency generation (DFG). The heart of the device is a periodically poled LiNbO3 waveguide with two poling sections, allowing two consecutive DFG steps in a single waveguide using just one pump laser. While comparable one-step conversions have been performed in the past (e.g. Dréau et al., Phys. Rev. Applied 9, 064031 (2018)), this two-step approach promises a far better signal-to-noise ratio while keeping coupling losses minimal.

Q 39.6 Wed 15:45 F342

Quantum light source based on two-photon interferences — •Martin Cordier, Max Schemmer, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

The transmission of coherent light through an optically dense ensemble has wide applications ranging from biology to chemical spectroscopy. Since the 18th century it has been commonly described by Beer-Lambert's law. Recently, it has been shown that, the light transmitted through an ensemble of two-level emitters is violated due to incoherent scattering at the single emitter level [1]. Here, building on the work of [2,3], we realize an interferometer that allows us to tune the quantum phase between the transmitted coherent and incoherent light fields. By tuning this phase we show interference fringes in the photon coincidence rate. Beyond clarifying the fundamental nature of what is commonly termed incoherently scattered light, our study lends itself to developing applications in quantum technologies, such as novel quantum light sources.

[1] Veyron et al., Phys. Rev. Research 4, 033033 (2022).
[2] Mahmoodian, et al., Physical Review Letters 121, 143601 (2018).
[3] Prasad et al., Nature Photonics 1 (2020).

Q 39.7 Wed 16:00 F342

Optimized integration of quantum emitters on the Silicon platform — •Lida Shamsafar[1], Thomas Weiss[1,2], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institute of Physics, University of Graz, and NAWI Graz, Graz, Austria

Stability and environmental control during operation is one of the necessary requirements desired for quantum-technological applications. The most promising way for such control of the surrounding is the direct integration of all required components on one chip. The most advanced and versatile platform for the implementation of highly complex and scalable photonic logic is the silicon platform. In this work, we utilize and optimize designs of photonic cavities in order to obtain high coupling efficiencies of quantum emitters to silicon waveguides. We will discuss how quantum emitter positioning will modify the light-matter interaction and how we can achieve best performance. Furthermore, radiation diagrams of TE and TM modes for the guided modes and free space modes are investigated in order to reduce radiative losses and maximize the coupling to the waveguides.

Q 39.8 Wed 16:15 F342

Single Mode Coupled Emission of Resonant Excited GaAs Quantum Dots — •Martin Kernbach[1,2], Julian Siller[1], Sophia Fuchs[1], and Andreas W. Schell[1,2] — [1]Leibniz Universität Hannover, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Quantum technologies like computing, QKD, or sensing demand for deterministic bright sources of single indistinguishable photons. In order to provide quantum light of isolated systems properly usable for quantum information science, an efficient excitation and extensive collection in a single mode is required. Single molecules and cavity confined quantum dots are convenient sources. The coupling to the excited state is maximized on resonance, but challenges the usability of the emitter due to the costs for the separation of the optical excitation mode from the mode of emission. A temporal, spacial, spectral, or combined method for separation is typically used. Here we present a realization of a single emitter under resonant excitation in a confocal setup coupled into a single mode fiber with the emission mode filtered by polarization. So far, a free beam is directed on the objective mounted with the scanning stages on a 1 m long stick in a liquid helium reservoir. For resonant cw excitation of GaAs semiconductor quantum dots a SNR of polarization suppression up to 100 and count rates of 280 kcps are archived by using a collecting lens with NA 0.68

only. Under this scheme further investigations regarding the blinking behavior are possible as well as probing alternative emitters like single molecules.

Q 40: Photonics II

Time: Wednesday 14:30–16:30 Location: F442

Q 40.1 Wed 14:30 F442

Bispectral High-Reflectivity Metamirrors — •Liam Shelling Neto[1], Johannes Dickmann[1], and Stefanie Kroker[1,2] — [1]TU Braunschweig, Institut für Halbleitertechnik, Braunschweig — [2]Physikalisch-Technische Bundesanstalt, Braunschweig

To manipulate electromagnetic waves in unique ways, metasurfaces, the two-dimensional variant of metamaterials, have opened up a whole new world of optical functionalities. From optical imaging to quantum optics, the full potential of metasurfaces depends heavily on their building blocks, i.e. metaatoms. To design metaatoms that meet tight requirements, as is the case in high-precision optical metrology, machine learning has shown promising results in the past years. Here we show preliminary results for implementing such a framework to design focusing metamirrors that provide high reflectivities for two different wavelengths. With high reflectivity and a tailored phase profile, such metamirrors could outperform conventional multilayer mirrors for high-precision optical interferometry due to their low thermal noise.

Q 40.2 Wed 14:45 F442

Light transport in designed symmetric multiple-scattering media — •Sudhir Saini[1], Kayleigh Start[1], Evangelos Marakis[2], and Pepijn Pinkse[1] — [1]MESA+ Institute for Nanotechnology, University of Twente, The Netherlands — [2]Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas, Crete, Greece

The latest advancement in nanofabrication technology enables the exact synthesis of designed scattering media with features on the scale of the optical wavelength. To the best of our knowledge, random scattering media with global symmetries do not naturally occur. Here we use modern nanofabrication to study the effect on light propagation of mirror-symmetric disorder in a multiple-scattering medium. A commercial direct laser writing technique based on two-photon polymerization is used to fabricate the designed three-dimensional (3D) mirror-symmetric disordered samples. Light transport experiments combined with quantitative 3D modeling are used to study the effect of mirror symmetry on the medium's scattering properties. The optical characterization results establish polarization-dependent deviations at the symmetry plane from the bulk ensemble-averaged intensity distribution when pumped in an equally mirror-symmetric way. In the weak-scattering limit, Drexhage's theory for the emission properties of an emitter above a mirror predicts the experimentally observed intensity patterns well. We model our experiments with FE numerical methods in the multiple-scattering regime. Applications are envisioned in fundamental light propagation studies and anti-counterfeiting.

Q 40.3 Wed 15:00 F442

Nonlocal optical response of finite hyperbolic metamaterials — •Olga Kochanowska[1,2] and Christin David[1] — [1]Institute of Condensed Matter Theory and Optics, Abbe Center of Photonics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Faculty of Physics, University of Warsaw, Pasteura Street 5, 02-093 Warsaw, Poland

Metamaterials are artificial nano-engineered structures with properties beyond those encountered in nature. Especially interesting are hyperbolic metamaterials (HMMs), i.e. highly anisotropic media characterized by a hyperbolic dispersion relation. HMMs exhibit unusual properties, such as negative refraction of light, with applications in subdiffraction imaging, refractometric sensing and photovoltaics. In our studies, a type II HMM (consisting of alternating metal and dielectric layers) was analyzed, using Finite-Difference Time-Domain (FDTD) and Fourier Modal Method (FMM) for numerical calculations. Initially, we assumed the local-response approximation (LRA), in which nonlocal effects are neglected. However, as in an HMM metal layers are of subwavelength thickness, the quantum nature of free electrons and their interactions in metals play a significant role and spatial dispersion effects are considered. Therefore, we implement the semi-classical hydrodynamic model into the FMM to account for nonlocal effects in hyperbolic gratings. Consequently, we compare the optical response of type II HMM in different geometries in the LRA and nonlocal case. We determine optimal parameters of the hyperbolic nanostructure at which nonlocal effects are relevant.

Q 40.4 Wed 15:15 F442

Low thermal noise meta-mirrors with 99.95 % reflectivity — •Johannes Dickmann[1], Steffen Sauer[1,2], Liam Shelling Neto[1], and Stefanie Kroker[1,2] — [1]Technische Universität Braunschweig, Institut für Halbleitertechnik, Langer Kamp 6a/b, 38106 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Many experiments in fundamental science are limited by the thermal noise of optical components, e.g. interferometric gravitational wave detectors, optical atomic clocks or cavity experiments on dark matter and general relativity. It has been found that, in addition to quantum noise, which can be reduced by using squeezed states of light, it is primarily Brownian noise of the mirror coatings that limit the sensitivity of the measurements. One way to reduce this noise is to use mirror layers with small mechanical losses, but these are difficult to find, especially at cryogenic temperatures. We present extensive investigations on microstructured mirror surfaces, i.e. meta-mirrors, for applications in high precision metrology. In particular, noise calculations and record-breaking experimental results of the reflectivities of these mirrors are presented.

Q 40.5 Wed 15:30 F442

Modeling beam imperfection using Hermite-Gauss modes for interferometric simulations — •Kevin Weber, Gudrun Wanner, and Gerhard Heinzel — Albert Einstein Institut, Hannover, Germany

Precision laser interferometry is a widespread technique used across many disciplines due to its high measurement accuracy. Using such a technique allows us to see the changes in earth*s gravitational potential, as in the GRACE-FO mission, or enables us to detect ripples in space-time itself, known as gravitational waves, as in LIGO or VIRGO. For future missions which deploy inter-spacecraft interferometers, the prior knowledge of all noise contributions is crucial for its success. Until now, most of our simulations use only perfectly Gaussian or tophat beam geometries. However, experimental beams never possess the mathematically perfect shape the models assume. In this talk, we will discuss possible sources of noise contributions from imperfect beam geometries. Also, we show possible means to predict those using a system of Hermite-Gaussian modes as mathematical beam descriptions.

Q 40.6 Wed 15:45 F442

Creation of Gauss-Bessel quasi-nondiffracting beams using Optical Vortices — •Maya Zhekova, Nikolay Dimitrov, and Alexander Dreischuh — Sofia University "St. Kliment Ohridski", Faculty of Physics

In recent years a way of creating Gauss-Bessel quasi-nondiffracting beams (GBBs) has been investigated, using optical vortices (OVs), which have been created and later annihilated. In and behind the focus of a thin lens, the resulting beam turns out to be such GBB. Different setups using spiral vortex plates (VPs) have been investigated, but their seemingly main weakness is the wavelength usage limited to the design wavelength of the VPs.

A novel scheme for laser beam shaping has been proposed and investigated, which is applicable in a wide range of wavelengths. The setup's key OV element is a single VP designed for 532 nm, which will be proven to transform beams at 445 nm, 532 nm, 633 nm and 800 nm into GBBs. We will show that this setup can transform beams into not only zeroth-order GB beams. In the case when a residual topological charge is left, the resulting beam will be a first-order Gauss-Bessel beam, again with a lack of spectral sensitivity.

Q 40.7 Wed 16:00 F442

Optical convolutional neural network with atomic nonlinearity — •Mingwei Yang[1,2], Elizabeth Robertson[1,2], Luisa Esguerra[1,2], Kurt Busch[3,4], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt, Institute of Optical Sensor Systems, Berlin, Germany. — [2]Technische Universität Berlin, Berlin, Germany. — [3]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Berlin, Germany. — [4]Max-Born-Institut, Berlin, Germany.

Due to their inherent parallelism, fast processing speeds and low energy consumption, free-space-optics implementations have been identified as an attractive possibility for analog computations of convolutions [1,2]. However, the efficient implementation of optical nonlinearities for such neural networks still remains challenging. In this work, we report on the realization and characterization of a three-layer optical convolutional neural network where the linear part is based on a 4f-imaging system and the optical nonlinearity is realized via the absorption profile of a cesium atomic vapor cell. This system classifies the handwritten digital dataset MNIST with 83.96% accuracy, which agrees well with corresponding simulations. [1] H. J. Caulfield and S. Dolev, *Why future supercomputing requires optics,* Nat. Photonics 4, 261*263 (2010). [2] M. Miscuglio, Z. Hu, S. Li, J. K. George, R. Capanna, H. Dalir, P. M. Bardet, P. Gupta, and V. J. Sorger, *Massively parallel amplitude-only fourier neural network,* Optica 7, 1812*1819 (2020).

Q 40.8 Wed 16:15 F442

Dispersion Interferometry for Relative Atmospheric Pressure Measurement — •Hugo Uittenbosch, Peter Mahnke, Raoul-Amadeus Lorbeer, and Oliver Kliebisch — Institute of Technical Physics, German Aerospace Center, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

Second harmonic interferometry is a common method in fusion research to measure dispersive phase shifts, i.e. for line-average electron densities [1]. Using this technique, a contact-less, relative barometer is implemented by measuring the pressure-dependent dispersive phase shift in air. This change in phase is converted into a change in pressure via the Ciddor equation [2]. In order to minimize the footprint of the experimental setup, a single crystal dispersion interferometer (SCDI) [3] is improved upon by generating a reference beam which contains both the fundamental and second harmonic beam coaxially, thereby reducing the system complexity. The device is used to measure changes in the dispersion of air in a pressurized chamber between 10^1 to 10^5 Pa and compared against a piezoresistive pressure transceiver. The deviation between both sensors was found to be less than 150 Pa.

[1] Drachev, V. P., et al. “Dispersion interferometer for controlled fusion devices.” Rev. Sci. Instrum. **64**(4) (1993)
[2] Ciddor, Philip E. “Refractive index of air: new equations for the visible and near infrared.” Appl. Opt. **35**(9) (1996)
[3] Lee, Dong-Geun, et al. “The new single crystal dispersion interferometer installed on KSTAR and its first measurement.” Rev. Sci. Instrum. **92**(3) (2021)

Q 41: Ultra-cold Atoms, Ions and BEC III (joint session A/Q)

Time: Wednesday 14:30–16:00 Location: F428

Q 41.1 Wed 14:30 F428

Dynamics of a single trapped ion in a high-density medium: A stochastic approach — Mateo Londoño[1], •Javier Madroñero[1], and Jesús Pérez-Ríos[2] — [1]Centre for Bioinformatics and Photonics (CIBioFi), Universidad del Valle, Cali, Colombia — [2]Department of Physics and Astronomy, Stony Brook University, Stony Brook, New York 11794, USA

Based on the Langevin equation, a stochastic formulation is implemented to describe the dynamics of a trapped ion in a bath of ultracold atoms, including an excess of micromotion. The ion dynamics is described following a hybrid analytical-numerical approach in which the ion is treated as a classical impurity in a thermal bath. As a result, the ion energy*s time evolution and distribution are derived from studying the sympathetic cooling process. Furthermore, the ion dynamics under different stochastic noise terms is also considered to gain information on the bath properties* role in the system*s energy transfer processes. Finally, the results obtained from this formulation are contrasted with those obtained with a more traditional Monte Carlo approach [1].

[1] Londoño M., Madroñero J., and Pérez-Ríos J., Phys. Rev A 106, 022803 (2022)

Q 41.2 Wed 14:45 F428

Competing non-superradiant Fermi-surface instabilities induced by cavity-mediated interactions — Bernhard Frank[1], •Michele Pini[2], and Francesco Piazza[2] — [1]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187, Dresden, Germany

The experimental realization of ultracold Fermi gases in optical resonators provides an interesting new platform to study unconventional quantum phases of matter induced by long-range cavity-mediated interactions. So far, mostly superradiant instabilities accompanied by charge density waves of the fermions have been studied in these systems. Here, we report instead on pair condensation instabilities, solving the competition problem within a controlled perturbative approach by exploiting the long-range nature of the cavity-mediated interaction. We show that a spin-polarized Fermi gas undergoes a phase transition to either a Cooper or a pair density wave superfluid at a common T_c. Below T_c, however, these phases turn out to be mutually exclusive, with one of them always dominating above the other. Moreover, these pairing instabilities occur both for attractive or repulsive interactions. This allows to observe them in the latter regime, where the superradiant instability is absent. In addition, the value of T_c is also found to be well within reach of the parameters of current experimental realizations, which is very promising for an experimental observation of these non-superradiant instabilities in the near future.

Q 41.3 Wed 15:00 F428

Proposal for a long-lived quantum memory using matter-wave optics with Bose-Einstein condensates in microgravity — •Elisa Da Ros[1], Simon Kanthak[1], Erhan Sağlamyürek[2,3], Mustafa Gündoğan[1], and Markus Krutzik[1,4] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]University of Calgary, Calgary, Canada — [3]University of Alberta, Edmonton, Canada — [4]Ferdinand-Braun-Institut (FBH), Berlin, Germany

Bose-Einstein condensates (BECs) are a promising platform for implementing optical quantum memories [1]. Most of the decoherence mechanisms that affect the lifetime of BEC-based memories can be compensated through conventional methods, but, ultimately, the density-dependent interatomic collisions set the upper limit on the lifetime to around 100~ms timescales. Here [2] we propose a new protocol that utilizes matter-wave optics techniques to minimize such density-dependent effects. Optical atom lenses first collimate and then refocus an initially expanding BEC. This allows performing the memory write-in and read-out operations at high density while decreasing the collision rate during the storage period. We show an expected memory lifetime in a microgravity environment of up to 100 s, which is ultimately limited by the background vacuum quality.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWK) under grant number No. 50WM2055.

[1] E. Sağlamyürek, et al., Nat. Photon. 12, 774-782 (2018).
[2] E. Da Ros, et al., arXiv:2210.13859 (2022).

Q 41.4 Wed 15:15 F428

Einstein-Elevator — •Alexander Heidt — HITec, Hannover, Niedersachsen

More and more people are striving to explore space and to colonize it as well as to use its advantages for basic research in physics. To be able to accomplish this, technologies are necessary that operate in special gravity conditions. With the motivation to develop and investigate such technologies, the Einstein-Elevator was built, which, in addition to simulating weightlessness, is able to simulate other gravity conditions. The advantages of the Einstein-Elevator are the high repetition rate of up to one hundred flights per day in combination with a weight of the payload of up to 1,000 kg for the experiment setup, which can have a diameter of up to 1.70 m and a height of 2 m. The duration of the gravity condition is four seconds and these can be adjusted between Lunar and Martian gravity down to microgravity. Currently, several projects are underway in various research fields, including the core research areas mechanical engineering and fundamental physics: In the area of fundamental physics research based on atom interferometry is carried out. Projects currently in progress include INTENTAS to measure the entanglement of atoms in microgravity with a compact sensor, with special requirements for stabilizing a magnetic field, and DESIRE to measure dark energy, where the motion, especially the rotation, of the Einstein elevator must be stabilized. In addition, the team is continuously developing the facility, opening up gravitational conditions that could not previously be simulated on Earth.

Q 41.5 Wed 15:30 F428

Statistically Suppressed Coherence in the Anyon-Hubbard Dimer — •Martin Bonkhoff, Imke Schneider, Axel Pelster, and Sebastian Eggert — Physics Departement and Research Center Optimas, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

The impact of statistical transmutation on superfluid tendencies is investigated for the Anyon-Hubbard dimer, a two-site restriction of the lattice generalization of Kundu anyons [1], experimentally accessible via the creation of density-dependent gauge phases and additional strong confinement [2]. We find a duality relation between the anyonic and the Bose-Hubbard dimer, which allows us to construct the corresponding, exact, algebraic Bethe-Ansatz solution. For large particle numbers and weak on-site interactions, the coherence properties are found to be strongly suppressed by statistical transmutation, with underlying mechanisms and applications analogous to one-axis spin-squeezing and entangled coherent states in quantum optics [3,4].

References:

[1] Bonkhoff, M. and Jägering, K. and Eggert, S. and Pelster, A. and Thorwart, M. and Posske, T., Phys. Rev. Lett. 126, 163201 (2021)

[2] Frölian, A., Chisholm, C.S., Neri, E. et al., Nature 608, 293-297 (2022)

[3] Kitagawa, M. and Ueda, M., Phys. Rev. A 47, 5138-5143 (1993)

[4] Rice, D. A., Jaeger, G. and Sanders, B. C., Phys. Rev. A 62, 012101 (2000)

Q 41.6 Wed 15:45 F428

Light-induced correlations in cold dysprosium atoms — •Marvin Proske[1], Ishan Varma[1], Nivedith Anil[1], Dimitra Cristea[1], Nico Bassler[2], Claudiu Genes[2,3], Kai Philipp Schmidt[2], and Patrick Windpassinger[1] — [1]Institut für Physik, JGU Mainz — [2]Department of Physics, FAU Erlangen-Nuremberg — [3]MPI for the Science of Light, Erlangen

When the average atomic distance in a cloud of ultracold atoms, is below the wavelength of the scattering light, a direct matter-matter coupling is introduced by electric and magnetic interactions. This alters the spectral and temporal response of the sample, where the atoms cannot be treated as individual emitters anymore. We intend to experimentally study light-matter interactions in dense dipolar media with large magnetic moments to explore the impact of magnetic dipole-dipole interactions onto the cooperative response of the sample. With the largest ground-state magnetic moment in the periodic table (10 Bohr-magneton), dysprosium is the perfect choice for these experiments.

This talk reports on the progess made in generating extremely dense cold dysprosium clouds. We discuss the measures taken to optically transport the atoms into a home-built science cell, which serves as a highly accessible platform to manipulate the atomic cloud. The small dimensions of the cell allow for extremely tight dipole trapping, enabled by a self-designed high NA objective. Further, we give a perspective on future measurements exploring collective effects in the generated atom cloud.

Q 42: Poster III

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

Q 42.1 Wed 16:30 Empore Lichthof

Fermionic coherent state path integral for ultrashort laser pulses and transformation to a field theory of coset matrices — •Bernhard Mieck — keine Institution

A coherent state path integral of anti-commuting fields is considered for a two-band, semiconductor-related solid which is driven by a ultrashort, classical laser field. We describe the generation of exciton quasi-particles from the driving laser field as anomalous pairings of the fundamental, fermionic fields. This gives rise to Hubbard-Stratonovich transformations from the quartic, fermionic interaction to various Gaussian terms of self-energy matrices; the latter self-energy matrices are solely coupled to bilinear terms of anomalous-doubled, anti-commuting fields which are subsequently removed by integration and which create the determinant with the one-particle operator and the prevailing self-energy. We accomplish path integrals of even-valued self-energy matrices with Euclidean integration measure where three cases of increasing complexity are classified (scalar self-energy variable, density-related self-energy matrix and also a self-energy including anomalous doubled terms). According to the driving, anomalous-doubled Hamiltonian part, we also specify the case of a SSB with hinge-fields which factorizes the total self-energy matrix by a coset decomposition into density-related, block diagonal self-energy matrices of a background functional and into coset matrices with off-diagonal block generators for the anomalous pairings of fermions. This allows to derive a classical field theory for the self-energy matrices of exciton quasi-particles by gradient expansions of the determinant.

Q 42.2 Wed 16:30 Empore Lichthof

Hybrid platform for quantum optic experiments — •Simon Haugg[1], Niklas Lettner[1], Lukas Antoniuk[1], Konstantin Fehler[1,2], Anna P. Ovvyan[3], Nico Gruhler[3], Valery A. Davydov[4], Viatcheslav N. Agafonov[5], Wolfram H. P. Pernice[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Moscow, Russia — [5]Universite F. Rabelais, 37200 Tours, France

In a hybrid approach, we are utilizing and manipulating the interaction of solid state quantum emitters in nano-hosts, such as color-centers in nano-diamonds, with classical Si_3N_4-based photonic crystal cavities, in order to yield an efficient spin-photon interface. We present our efforts to realize this goal, which paves the way to a realization of integrated on-chip hybrid quantum systems.

Q 42.3 Wed 16:30 Empore Lichthof

Orbital angular momentum modes generated in the parametric down-conversion process with a non-Gaussian pump — •Lucas Gehse, Dennis Scharwald, and Polina Sharapova — Universität Paderborn, Paderborn, Germany

Electric fields can carry two types of angular momentum. The first is the spin angular momentum, which arises from the polarization of the light, and the second is the orbital angular momentum (OAM) which arises from the light phase distribution. OAM modes have an unlimited basis, which makes them very promising for fast and efficient quantum information and communication protocols [1]. It has recently been shown that a radially symmetric parametric down-conversion (PDC) process is a good source of photons with perfectly anti-correlated orbital numbers in both low- and high-gain regimes [2]. In this work, we investigate an SU(1,1) interferometer consisting of two PDC sources, which are two nonlinear crystals pumped by a Laguerre–Gaussian pump with different orbital and radial numbers. We consider various crystal lengths, pump widths and distances between the crystals, in order to find configurations with high-order OAM modes populated. We have found configurations in which up to 120 OAM modes can be generated using a pump with different orbital numbers. Mode shapes and intensity profiles for various configurations of the SU(1,1) interferometer in the low- and high-gain regimes were investigated and discussed.

[1] Manuel Erhard *et al.*, Light Sci Appl **7**, 17146 (2018)

[2] Lina Beltran *et al.*, J. Opt. **19**, 044005 (2017)

Q 42.4 Wed 16:30 Empore Lichthof

An Experimental Setup to Study Amplification Without Inversion in Mercury — •Daniel Preissler and Thomas Walther

— TU Darmstadt, Institute for Applied Physics, Laser and Quantum Optics, Schlossgartenstr. 7, D-64289 Darmstadt

For conventional laser sources, the required power to achieve the necessary population inversion scales with at least the fourth power of the laser frequency. This severaly limits the generation of lasers at short ultraviolet wavelengths and below. To overcome this problem, the coherent reabsorption can be suppressed by carefully employing atomic coherence effects. This is called lasing without inversion (LWI).

In a recent publication Rein et al. (Phys Rev. A **105** (2022) 023722) showed an experimental setup to study an LWI scheme in atomic mercury vapor, consisting out of two driving lasers at 435.8nm and 546.1nm, a repumper at 404.7nm and a probe system which doubles as a pump source at 253.7nm. This allowed for the further refinement of a theoretical model and its comparison with experimental data.

Based on this model, critical parameters towards achieving amplification withouth inversion (AWI) - a prerequisite for LWI - could be identified through simulations. This includes the power and spectral width of the pump system and the power of the strong driving field at 435.8nm.

In this contribution the results of those simulations as well as the experimental steps taken to improve on those parameters will be presented. Additionally, measurements of the observed three photon coherence effect will be discussed.

Q 42.5 Wed 16:30 Empore Lichthof

Rydberg Dark States on an Atom Chain Interacting with a Chiral Waveguide — •Tom von Scheven[1], Anne V. Jeschke[1], Igor Lesanovsky[1,2], and Beatriz Olmos[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We consider a laser-driven chain of atoms coupled to a chiral waveguide and investigate the possibility of creating so-called dark states, i.e. eigenstates of the atomic chain where the photons become trapped. Beyond their fundamental interest, atomic systems that host such dark states are nowadays widely investigated due to their potential applications in quantum information processing, e.g., as quantum memories. It has been previously found that, under the right combination of atomic and laser parameters, product states of entangled pairs (so-called dimer states) can be excited in a chain of two-level systems coupled to a chiral waveguide. Here, we analytically and numerically demonstrate the existence of a new class of entangled dark states by exploiting the strong interactions present in a chain of Rydberg atoms close to a waveguide. Compared to the dimer states, the conditions on the laser parameters necessary to excite a dark state (e.g. detuning pattern) are less restrictive. Moreover, these Rydberg dark states possess entanglement that is shared among all atoms are more robust against external perturbations, such as dissipation into unguided modes. Our results demonstrate the potential of using Rydberg atoms in quantum optical many-body systems in order to create dark states.

Q 42.6 Wed 16:30 Empore Lichthof

Modified dipole-dipole interactions in the presence of a nanophotonic waveguide — •Mathias Bo Mjøen Svendsen[1] and Beatriz Olmos[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

When an emitter ensemble interacts with the electromagnetic field, dipole-dipole interactions are induced between the emitters. The magnitude and shape of these interactions are fully determined by the specific form of the electromagnetic field modes. If the emitters are placed in the vicinity of a nanophotonic waveguide, such as a cylindrical nanofiber, the complex functional form of these modes makes the analytical evaluation of the dipole-dipole interaction cumbersome and numerically costly. In this work, we provide a full detailed description of how to successfully calculate these interactions, outlining a method that can be easily extended to other environments and boundary conditions. Such exact evaluation is of importance as, due to the collective character of the interactions and dissipation in this kind of systems, any small modification of the interactions may lead to dramatic changes in experimental observables, particularly as the number of emitters increases. We illustrate this by calculating the transmission signal of the light guided by a cylindrical nanofiber in the presence of a nearby chain of emitters.

Q 42.7 Wed 16:30 Empore Lichthof

Organic dye molecules as possible candidates for spin-photon interfaces — •Max Masuhr and Daqing Wang — Institute of Physics, University Kassel, Heinrich-Plett-Straße 40, Kassel, Germany

Polycyclic hydrocarbon molecules are bright photon emitters, exhibiting high quantum efficiencies and narrow transition linewidths when embedded in matrices and cooled to liquid helium temperatures. The synthetic flexibility of molecules allows for tuning of their emission wavelengths and makes them promising candidates for linking with other quantum systems. Apart from the favorable photon emission properties between the singlet states, the long-lived triplet states in these molecules provide opportunities for quantum information storage. Here, we discuss lifetime measurements of the triplet states and investigate the feasibility of realizing a spin-photon interface based on the singlet-triplet transition in a single molecule.

Q 42.8 Wed 16:30 Empore Lichthof

Fiber-coupled plug-and-play heralded single photon source based on Ti:$LiNbO_3$ **and polymer technology** — •Christian Kiessler[1], Hauke Conradi[2], Moritz Kleinert[2], Viktor Quiring[1], Harald Herrmann[1], and Christine Silberhorn[1] — [1]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn — [2]Fraunhofer HHI Berlin, Einsteinufer 37, 10587 Berlin

A reliable, but cost-effective generation of single-photon states is key for practical quantum communication systems. Requirements like affordability, stability, miniaturized design and fiber compatibility are essential for these sources.

Here, we present the first chip-size fully integrated fiber-coupled Heralded Single Photon Source (HSPS) module based on a hybrid integration of Lithium-Niobate into a polymer board. A spontaneous parametric down conversion (SPDC) process with a pump wavelength of 532 nm leads to signal and idler of 810 nm and 1550 nm. The module has a size of $(2 \times 1)\,\mathrm{cm}^2$ and is fully fibercoupled with one pump input fiber and two output fibers for separated signal and idler. We measure a heralded second-order correlation function of $g_h^{(2)} = 0.05$ with a heralding efficiency of $\eta_h = 4.5\,\%$ at low pump powers.

Q 42.9 Wed 16:30 Empore Lichthof

Purcell-Enhanced Emission from Individual Color Center in Diamond to Photonic Crystal Cavities — •Lukas Antoniuk[1], Konstantin Fehler[1,2], Niklas Lettner[1,2], Anna P. Ovvyan[3,5], Richard Waltrich[1], Nico Gruhler[3], Viatcheslav N. Agafonov[4], Wolfram H.P. Pernice[3,5], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Universite F. Rabelais, 37200 Tours, France — [5]Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Classical photonic platforms combined with solid state quantum emitters, like the SiV^- center in diamond, enable for efficient quantum photonic devices. In a hybrid approach, we combine the SiV^- center in nanodiamonds with an efficient on-chip Photonic Crystal Cavity based on a Si_3N_4 photonic platform [1]. Utilizing an atomic force microscope, we developed a routine for placing and optimization of the emitter inside the mode of the cavity. For individual optical transitions of a single SiV^- center we achieved a Purcell enhancement of more than 4 as well as lifetimes as short as 450 ps [2].

[1] Fehler, Konstantin G., et al. ACS Nano 2019, 13, 6, 6891-6898.
[2] Fehler, Konstantin G., et al. ACS Photonics 2021, 8, 9, 2635-2641.

Q 42.10 Wed 16:30 Empore Lichthof

Optical Characterization of InGan/Gan-based nanowires — •Mohsen Esmaeilzadeh[1,2], Pablo Tieben[1,2], Soumyadip Chatterjee[3], Apurba Laha[3], and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Institute for Solid State Physics, Leibniz University Hannover, 30167 Hannover — [3]Department of Electrical Engineering, Indian Institute of Technology Bombay,400076 Mumbai

Recent progress has been achieved in using GaN-based nanostructures as LEDs. GaN as a semiconductor exhibits great thermal and chemical stability and the potential for tuning the band gap by alloying with indium over visible wavelengths.

Indium composition in growing InGaN is very sensitive to temperature. The compositional non-uniformity in InGaN impacts the emission wavelength of the InGaN nanostructures. We are specifically investigating the optical properties of single InGaN/GaN-based nanowires grown on Si (111) substrate using RIBER MBE C21 system equipped with a Veeco plasma cell.

A high resolution SEM microscope was used to investigate the morphology and structure of single nanowires. We used confocal fluorescence microscopy technique to determine the corresponding optical emission properties for a broad range of excitation wavelengths in the visible spectrum. Moreover, we studied the possible damage threshold of the nanowires by exposing them to high laser power for an extended period of time and observing the stability of the emission. Simultaneously, we monitored the corresponding fluorescence spectrum.

Q 42.11 Wed 16:30 Empore Lichthof

A quantum Rabi model with two interacting qubits — •Thomas J. Hamlyn[1,2] and Weibin Li[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, United Kingdom

We study a modified quantum Rabi model with a monochromatic bosonic mode and two qubits coupled via a spin-spin interaction. We focus on eigenstates of the model in two different regimes. Without qubit mixing, the Hilbert space can be divided into two symmetry sectors. It is found that the model can be reduced to the standard Rabi model, and therefore the eigenenergy can be obtained systematically through solving the so-called $\mathcal{G}$-function. With the qubit mixing, we study the superradiant phase transition with the mean field and direct diagonalization method, both giving consistent results. It is found that the symmetry of the ground state is broken. We explore the symmetry breaking by varying system parameters. Using a variety of methods, we show the dependence of the symmetry breaking on the qubit mixing

Q 42.12 Wed 16:30 Empore Lichthof

Optical properties of InGaN quantum dot embedded on GaN nanowire — •Hiren Dobariya[1], Pablo Tieben[1,2], Swagata Bhunia[3], Suddhasatta Mahapatra[3], Apurba Laha[3], and Andreas W. Schell[1,2] — [1]Institute for Solid State Physics, Gottfried Wilhelm Leibniz University, 30167 Hannover — [2]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [3]Department of Electrical Engineering, Indian Institute of Technology Bombay, 400076 Mumbai

III-Nitride group-based materials, particularly Indium Gallium Nitride (InGaN) have emerged as one of the most critical materials for various applications, such as solid-state lighting, quantum technology, and scientific research. The unique nanostructure of GaN nanowires with quantum dots of InGaN embedded has been in focus for near-UV photonics research in general, as well as its room-temperature single photon generation. In this work, we present the detailed optical characterization of InGaN quantum dots embedded in GaN nanowires, grown by Plasma Assisted Molecular Beam Epitaxial (PAMBE) technique to realize sub-10 nm InGaN quantum dots exhibiting strong quantum confinement. We have carried out a detailed study on the optical characterizations of the InGaN quantum dots (QDs) in a home-built confocal microscope setup. The photoluminescence properties of the InGaN quantum dot at room temperature and cryogenic temperatures show strong emissions ranging from the green to red in the electromagnetic spectrum.

Q 42.13 Wed 16:30 Empore Lichthof

Machine-learning optimized entanglement in photonic topological insulators — •Saipavan Vengaladas[1,2], Armando Pérez-Leija[4], Kurt Busch[1,3], and Konrad Tschernig[4] — [1]Max-Born-Institut, 12489 Berlin, Germany — [2]Department of Physics, Freie Universität Berlin, 14195 Berlin, Germany — [3]Humboldt-Universität zu Berlin, AG Theoretische Optik & Photonik, 12489 Berlin, Germany — [4]CREOL/College of Optics & Photonics, University of Central Florida, Orlando, 32816 FL, USA

Photonic Floquet topological insulators feature so-called edge states, and wavepackets built from edge states are topologically protected. As a result, they naturally resist the scrambling effects of disorder and retain their shape during propagation. This useful property gives rise to the intriguing possibility of protecting two-photon entangled states. While the necessary conditions to protect two-photon entanglement in topological insulators (TIs) have been well established[1], it is yet unclear how to construct optimally entangled two-photon states. This is no trivial task since the degree of entanglement, and the amount of bulk scattering are naturally competing properties inside TIs. In this work, we take a more general approach by defining a black-box optimization problem, which is tackled using a machine-learning based Latent Action Monte Carlo Tree Search (LA-MCTS) meta-algorithm[2]. We present the optimized states that we obtain by exploring the space of all possible states and discuss their properties. [1] K.Tschernig et al., Nat. Commun.12, 1974 (2021). [2] arxiv.org/abs/2007.00708

Q 42.14 Wed 16:30 Empore Lichthof

On-chip single-photon subtraction by individual silicon vacancy centers in a laser-written diamond waveguide — Michael Koch[1,2], •Vibhav Bharadwaj[1,3], Michael Höese[1], Johannes Lang[1], John P. Hadden[4], Roberta Ramponi[3], Fedor Jelezko[1,2], Shane M. Eaton[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Ulm, Germany — [2]IQst, Ulm University, D-89081 Ulm, Germany — [3]Istituto di Fotonica e Nanotecnologie (IFN-CNR), Milan, Italy — [4]School of Physics and Astronomy, Cardiff University, Cardiff CF24 3AA, UK

Apart from its perfect to application properties of hardness, transparency and thermal conductivity, diamond has created an interest in the quantum technologies community due to naturally occurring imperfection in the form of color centers such as Nitrogen vacancy (NV) and Silicon Vacancy (SiV). They have emerged as candidates for quantum computing and field sensing applications. Recently, Laser writing has allowed 3-d formation of photonic and microfluidic devices in diamond [1] with the ability to integrate waveguide with Ion implanted single SiV centers. In this poster, we show single-emitter extinction measurements from SiV coupled to a waveguide demonstrating single-photon subtraction from a quasi-coherent field resulting in super-Poissonian light statistics[2]. Our architecture enables light field engineering in an integrated design on the single quantum level.

[1] Bharadwaj V et al. Journal of Physics: Photonics (2019): 022001
[2] M. K. Koch et al., ACS Photonics 9, 3366-3373 (2022)

Q 42.15 Wed 16:30 Empore Lichthof

Sum-frequency generation in diced ridge waveguides in periodically poled $LiNbO_3$ — •Noel Heinen, Christian Kiessler, Michelle Kirsch, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn

In order to make quantum technology commercially usable, it must be integrated into the existing optical C-band fiber network. However, there are devices based on nitrogen vacancies in diamonds with an operating wavelength of 639 nm, which therefore require a frequency converter interface. Here, we demonstrate a SFG process in titanium indiffused diced ridge waveguides in periodically poled $LiNbO_3$ for a conversion of 1550 nm and 1064 nm pump wavelengths to 630 nm. We performed simulations and mode field measurements to analyse the light guiding conditions of the waveguides and to find optimum fabrication parameters, since dicing of waveguides with a dicing saw is a new fabrication method in our group. We measure transmission losses below $0.8\,\frac{\mathrm{dB}}{\mathrm{cm}}$ and a normalized SFG conversion efficiency of $\eta_{\mathrm{norm}} = 7.4\,\frac{\%}{\mathrm{W\cdot cm^2}}$ at pump powers of a few milliwatts.

Q 42.16 Wed 16:30 Empore Lichthof

Open-system dynamics and fluctuation-dissipation relation in a photon Bose-Einstein condensate — •Aleksandr Sazhin[1], Göran Hellman[1], Fahri Emre Öztürk[1], Frank Vewinger[1], Johann Kroha[2], Vladimir Gladilin[3], Michiel Wouters[3], Martin Weitz[1], and Julian Schmitt[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]Physikalisches Institut, Universität Bonn, Nussallee 12, D-53115 Bonn — [3]TQC, Universiteit Antwerpen, Universiteitsplein 1, B-2610 Antwerpen

The tuneable openness of optical quantum gases, as photon or polariton condensates in optical microcavities, enables the exploration of new system states and phases, which would not be accessible under closed system conditions. Here, we experimentally demonstrate a non-Hermitian phase transition in a photon Bose-Einstein condensate in an open dye-filled optical microcavity. The transition separates a phase of biexponential photon number correlations from both lasing and an intermediate, oscillatory regime, as characterised by the second-order correlation dynamics of the BEC [1]. By studying the magnitude of the condensate number fluctuations and relating them to a response function, we verify a fluctuation-dissipation relation for the BEC coupled to a molecular reservoir [2]. In more recent work, we have extended these studies to the time domain, establishing a connection between the fluctuation dynamics and the response of the condensate population to an external pulse-like perturbation of the molecular reservoir. [1] F. E. Öztürk et al., Science 372, 88 (2021) [2] F. E. Öztürk et al., arXiv:2203.13255 (2022)

Q 42.17 Wed 16:30 Empore Lichthof

Integrated Photonics for Quantum Computing and Communication — •Jonas Zatsch[1,3], Jeldrik Huster[1,3], Simon Abdani[1,3], Christian Schweikert[2], and Stefanie Barz[1,3] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany — [2]Institute of Electrical and Optical Communications Engineering, University of Stuttgart, 70569 Stuttgart, Germany — [3]Center for Integrated Quantum Science and Technology (IQST)

Future quantum information research aims at the realisation of computationally powerful quantum computers and the secure implementation of quantum communication protocols. This requires an increasing number of components with small footprint, high phase stability and low-loss connectivity. A promising scalable technology is integrated quantum photonics, allowing for a compact and robust manipulation of photonic quantum bits. We present an integrated photonic chip, based on the silicon-on-insulator platform, enabling photonic quantum information processing. We demonstrate the generation of photonic quantum states on chip using integrated beam splitters and phase shifters. We show the conversion of quantum information from one degree of freedom – path – to another – polarisation – and vice versa. Combining this conversion with efficient fibre coupling allows one to connect several chips and thus the implementation of networked protocols for quantum communication and quantum computing.

Q 42.18 Wed 16:30 Empore Lichthof

Generalized Description of the Spatio-Temporal Biphoton State in Spontaneous Parametric Down-Conversion — •Baghdasar Baghdasaryan[1,2], Carlos Sevilla-Gutiérrez[3], Fabian Steinlechner[3,4], and Stephan Fritzsche[1,2,4] — [1]Theoretisch-Physikalisches Institut, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [4]Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany

Spontaneous parametric down-conversion (SPDC) is a widely used source for photonic entanglement. Years of focused research have led to a solid understanding of the process, but a cohesive analytical description of the paraxial biphoton state has yet to be achieved. We present a simple-to-use closed expression for the biphoton state. The approach describes the full spectral and spatial properties of all interacting beams and applies to a wide range of experimental settings. The analytical treatment of the biphoton state decomposed into discrete Laguerre Gaussian (LG) modes also provides a deeper insight into the role of the Guoy phase in PDC. Especially, the coupling strength of spatial and spectral degrees of freedom (DOF) in PDC is fully controlled by the Gouy phase of pump, signal and idler beam. The control over the Gouy phase can be used to engineer entangled state separable in spatial and spectral DOF.

Q 42.19 Wed 16:30 Empore Lichthof

Generalized Ramsey Protocols — •Maja Scharnagl — Institute for theoretical physics, Leibniz University Hannover, Germany

We consider a variational class of generalized Ramsey protocols with two one-axis-twisting (OAT) operations, one before and one after the phase imprint, for which we optimize the direction of the signal imprint, the direction of the second OAT interaction and the measurement direction via a numerical routine for global optimization of constrained parameters. In doing so, we distinguish between protocols whose signal from spin projection measurements exhibits a symmetric or antisymmetric dependence on the phase to be measured. We find that the Quantum Fisher Information, which bounds the sensitivity achievable with a one-axis-twisted input state, can be saturated in our variational class of protocols for nearly all initial squeezing strengths. Therefore, the generalized Ramsey protocols considered here allow us to reduce quantum projection noise in comparison to the standard Ramsey protocol considerably.

Q 42.20 Wed 16:30 Empore Lichthof

Development of a stable, compact and cost-effective laser light source for resonant control of tin-vacancy color centres — •Franziska Marie Herrmann[1], Joseph Hugh Deakin Munns[1], Cem Güney Torun[1], and Tim Schröder[1,2] — [1]Integrated Quantum Photonics, Institut für Physik, Humboldt-Universität zu Berlin — [2]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Tin-vacancy colour centres in diamond are promising candidates for nodes in quantum networks, due to their suitable optical and spin properties. However, with a zero phonon line wavelength of 619 nm, resonant excitation cannot be achieved easily by commercially available and affordable laser systems. At 1238 nm however, narrowband lasers are commercially available and the targeted 619 nm can be reached by frequency doubling. Here we introduce a stable and cost-effective lasersystem relying on second harmonic generation for resonant quantum control of tin vacancy centres, describe the stabilization measures taken and demonstrate the functionality of the system by driving all-optical rabi oscillations.

Q 42.21 Wed 16:30 Empore Lichthof

Properties of SiV centers in nanodiamonds for quantum networks — •Richard Waltrich[1], Marco Klotz[1], Niklas Lettner[1], Lukas Antoniuk[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Universität Ulm — [2]Universite Francois Rabelais de Tours

The realization of a quantum network is of major interest. Combining the good optical and spin properties of group IV defects in diamond with established technologies in photonic-structure production puts such a platform into reach. We present measurements of characteristic properties of SiV centers in nanodiamond in comparison with bulk diamond, showing key features for the realization of a quantum network node.

Q 42.22 Wed 16:30 Empore Lichthof

Characterization of an ultra broadband integrated MIR photon pair source — •Abira Gnanavel, Franz Roeder, Olga Brecht, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Broadband photon-pairs from parametric down-conversion (PDC) are of interest for spectroscopy at low light levels and applications such as entangled two-photon absorption.

Here, we present the design and characterization of periodically poled lithium niobate waveguides to generate ultra-broadband, non-degenerate photon pairs via type II PDC in the near-infrared and mid-infrared regime. We especially engineer the dispersion of those waveguides regarding the quasi-phase matching condition.

We present a condition where the signal and idler photons are group velocity matched and furthermore group velocity dispersion matched that is, they propagate at the same velocity but incur opposite amounts of chirp. The photons are generated in a periodically poled titanium-indiffused lithium niobate waveguide at wavelengths of 800nm and 2800nm, well suited for detection and MIR probing. We expect a spectral bandwidth exceeding 27 THz for this process when pumping with a low-cost cw laser diode. A higher bandwidth in the frequency domain results in tighter correlations in the time domain and thus an increased photon simultaneity, which is desirable for ultrafast spectroscopy applications because it enables better measurement precision.

Q 42.23 Wed 16:30 Empore Lichthof

Quantum Fluctuation Forces between Trapped Nanospheres — •Clemens Jakubec[1], Kanupriya Sinha[2], Uros Delic[1], and Pablo Solano[3] — [1]Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [2]School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, AZ 85287-5706, USA — [3]Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Concepción, Concepción, Chile

We present an analysis of the quantum fluctuation forces between two dielectric nanospheres trapped via optical tweezers. We develop a full quantum description of the radiative forces between the two nanospheres considering their mutual interaction mediated via the classical trapping field and the quantum fluctuations of the electromagnetic field. An analysis of the three separate contributions to the total potential – the Casimir-Polder potential, the classical trap potential and the optical binding potential – is presented. The total potential is subsequently studied as a function of various parameters, such as the tweezer field intensity and phase, demonstrating that, for appropriate sets of parameters, there exists a mutual bound state of the two nanospheres which can be ∼ 1000 K deep. Our results are pertinent to ongoing experiments with trapped nanospheres in the macroscopic quantum regime.

Q 42.24 Wed 16:30 Empore Lichthof

Characterization of an ultra-broadband integrated MIR photon pair source — •Abira Gnanavel, Franz Roeder, Olga Brecht, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Broadband photon-pairs from parametric down-conversion (PDC) are of interest for spectroscopy at low light levels and applications such as entangled two-photon absorption.

Here, we present the design and characterization of periodically poled lithium niobate waveguides to generate ultra-broadband, non-degenerate photon pairs via type II PDC in the near-infrared and mid-infrared regime. We especially engineer the dispersion of those waveguides regarding the quasi-phase matching condition.

We present a condition where the signal and idler photons are group velocity matched and furthermore group velocity dispersion matched that is, they propagate at the same velocity but incur opposite amounts of chirp. The photons are generated in a periodically poled titanium-indiffused lithium niobate waveguide at wavelengths of 800nm and 2800nm, well suited for detection and MIR probing. We expect a spectral bandwidth exceeding 27 THz for this process when pumping with a low-cost cw laser diode. A higher bandwidth in the frequency domain results in tighter correlations in the time domain and thus an increased photon simultaneity, which is desirable for ultrafast spectroscopy applications because it enables better measurement precision.

Q 42.25 Wed 16:30 Empore Lichthof

Photon correlations of trapped calcium ion crystal — •Zyad Shehata, Stefan Richter, Manuel Bojer, and Joachim von Zanthier — FAU Erlangen-Nürnberg, Quantum Optics and Quantum Information, Staudtstr. 1, 91058 Erlangen, Germany

Trapped ions are an important resource for quantum information science. Here, we study the collective light emission of trapped calcium ion crystals, in particular the photon auto- and cross-correlations. Simultaneous photon bunching and anti-bunching emerge from such systems [1]. In this work, we focus on the first-, second-, and third-order correlation functions of two- and three-ion crystals taking into account concrete experimental conditions, in particular the contrast-reducing Debye-Waller factor. Various illumination schemes of the ions are discussed in the context of the trap geometry, getting analytical and numerical solutions for the second- and third-order correlation functions, including predictions for their signal-to-noise ratio.

[1] S. Wolf, S. Richter, J. von Zanthier, F. Schmidt-Kaler, Light of Two Atoms in Free Space: Bunching or Antibunching?, Phys . Rev, Lett. 124, 063603 (2020)."

Q 42.26 Wed 16:30 Empore Lichthof

Cryogenic ensemble spectroscopy of Europium molecular complexes — •Weizhe Li, Evgenij Vasilenko, Jannis Hessenauer, Senthil Kumar Kuppusamy, Mario Ruben, and David Hunger — Karlsruhe Institut für Technologie, Karlruhe, Germany

Rare Earth Ions (REI) doped into solid state crystals have long optical coherence time and even longer spin coherence time. This makes REI a promising candidate for spin qubits which are optically addressable. For integration into photonic structures, nano-scale materials are of particular interest. In Europium-doped nanocrystals (Eu^{3+}:Y_2O_3), an optical coherence time of 3.7 μs and spin coherence time of 3 ms were obtained [1, 2, 3]. More recently, crystallized molecular complexes hosting REI have shown excellent optical coherence lifetimes of more than 10 μs and long spin population lifetimes [4], evidencing a quiet local environment.

This opens up a promising direction to explore further. In our research, we investigate different Eu^{3+}-based molecules including the complex used in [4]. We perform cryogenic ensemble spectroscopy and spectral hole burning and consistently observe long-lived spin states and narrow homogeneous optical linewidths.

[1] J. Bartholomew et al. Nano letters 17.2(2017), pp. 778-787.
[2] A. Perrot et al. Physical review letters 111.20 (2013), p. 203601.
[3] D. Serrano et al. Nature communications 9.1 (2018), pp. 1-7.
[4] D. Serrano et al. Nature 603.7900 (2022), pp. 241-246.

Q 42.27 Wed 16:30 Empore Lichthof

Cryogenic characterization of Electrical circuits — •Anupam Kumar, Niklas Lamberty, Thomas Hummel, and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

Electrical components are typically optimized for operation near room temperature. Using these components for quantum photonics applications in the future will likely require operation at cryogenic temperatures since the measurement is often performed using superconducting detectors.

In this work, we characterize different electrical components made of various semiconductor platforms such as SiGe, GaAs, and InGaP. These commercial components are characterized at 4K and compared to each other for optimal performance. This allows the design of front-end electrical circuitry for SNSPDs, leading up to a single IC design.

Q 42.28 Wed 16:30 Empore Lichthof

Feed-forward for optical circuits with cryogenic electronics — •Niklas Lamberty, Thomas Hummel, Frederick Thiele, and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

Many quantum optical experiments require high purity single-photon states. For this purpose, we developed a cryogenic electronic feed-forward circuit for selection of single-photon states from a PDC source. The photon number is measured using a photon number resolving superconducting detector array operated at 1 K and evaluated by an amplifier and a logic circuit based on SiGe Heterojunction Bipolar Transistor and CMOS technology. The circuit is operated in a cryostat at 2.5 K.

A total signal delay of (59 ± 7) ns and a heatload of more than 5 mW was measured. The circuit achieved reliable selection of single photon detection events, when tested with a coherent state, and creates signals usable for a modulator driver.

Q 42.29 Wed 16:30 Empore Lichthof

Quantumness and speedup limit of a qubit under transition-frequency modulation — •Amin Rajabalinia[1], Mahshid Khazaei Shadfar[2,3], Farzam Nosrati[2,3], Ali Mortezapour[1], Roberto Morandotti[3], and Rosario Lo Franco[2] — [1]Department of Physics, University of Guilan, P. O. Box 41335-1914, Rasht, Iran — [2]Dipartimento di Ingegneria, Universit'a di Palermo, Viale delle Scienze, 90128 Palermo, Italy — [3]INRS-EMT, 1650 Boulevard Lionel-Boulet, Varennes, Quebec J3X 1S2, Canada

we investigate the ability of a frequency-modulated qubit embedded in a leaky cavity to maintain quantumness. To detect quantum coherence as the main distinguishing feature of the quantum world from the classical one, tomographic methods are used to reconstruct the density matrix of quantum systems. Although the implementation of such a strategy poses a technical challenge in terms of experimental measurement settings, Leggett-Garg inequality and quantum witness have been introduced as quantum indicators to quantify the nonclassicality of a system in order to overcome the complexity of detection in the experiment. The quantum witness is based on the classical no-signaling-in-time assumption, which states that a previous experiment has no effect on the statistical outcome of the subsequent experiment. We compare a standard quantum witness (SQW) and a recently introduced optimized quantum witness (OQW) as experimentally friendly figures of merit [Phys. Rev. A 101, 012331 (2020)]. The OQW successfully identifies quantum coherence protection via frequency modulation, whereas the SQW fails.

Q 42.30 Wed 16:30 Empore Lichthof

Towards the observation of collective radiance phenomena in a one-dimensional array of waveguide-coupled atoms with sub-$\lambda/2$ spacing — •Lucas Pache, Martin Cordier, Max Schemmer, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, Germany

Recently, it has been shown theoretically that the infidelity of photon storage and retrieval in quantum memories scales exponentially better with the number of emitters if one harnesses the collective response of closely spaced atomic arrays [1,2]. This improved scaling relies on the effect of selective radiance, i.e., destructive interference of scattering into undesired modes. This occurs when the mean distance in a periodic array of emitters is smaller than half of the atomic resonant wavelength ($d < \lambda/2$). In order to realize this situation, we trap and optically interface laser-cooled cesium atoms using a two-color nanofiber-based dipole trap which is composed of a blue-detuned partial standing wave and a red-detuned running wave light field. The resulting trapping potential consists of one-dimensional trapping sites which are spaced by $d \simeq 0.37\lambda$. We characterize this trapping configuration by measuring the trap frequencies as well as the lifetime and the total number of the trapped atoms.

[1] A. Asenjo-Garcia et al. PRX 7, 031024 (2017)
[2] M. Manzoni et al. NJP 20, 083048 (201

Q 42.31 Wed 16:30 Empore Lichthof

Multimode squeezed states in coherent optical time-frequency networks — •Patrick Folge, Matteo Santandrea, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Linear optical quantum networks are powerful tools in modern quantum applications and have gained a lot of attention due to their role in proving quantum computational advantages. Here, we present a resource efficient method for the implementation of linear optical quantum networks in a high-dimensional time-frequency encoding. We consider a multimode squeezing source based on type-0 parametric down-conversion (PDC) in the high gain regime as the quantum input of the system. To implement a linear optical network in the frequency bin basis we consider the use of a so-called quantum pulse gate (QPG), which allows for time-frequency mode selective frequency conversion. Here, the QPG is applied to coherently filter out input bins from the multimode squeezed state and superimpose them on the output ports of the QPG. This allows for the implementation of fully programmable linear quantum networks on the frequency bin basis. Here, we present our theoretical modeling of this system by applying it to the simple case of a frequency beam splitter. In this modelling we find that wider coherent filtering of the selected bins improves the performance of the network.

Q 42.32 Wed 16:30 Empore Lichthof

A few-MHz linewidth tunable optical filter based on a fibre-ring-resonator — •Gabriele Maron, Xinxin Hu, Luke Masters, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

We present a design for an ultra-narrowband, tunable optical filter, which is based on a fibre ring resonator. It consists of a fibre coupler with a variable splitting ratio, which allows us to set the filter linewidth and on-resonance transmission. At the same time, we set and actively stabilize the central frequency of the filter by means of actuators that change the optical round trip length of the fibre-ring. Operated in a notch-filter configuration, we recently used this device to isolate and investigate the incoherent emission from a single optically trapped atom, which was excited with near-resonant laser light [1]. The addition of a second variable fibre coupler into the fibre-ring extends the device's utility for filtering in an add-drop configuration. In this case, our characterisation reveals a resonator linewidth significantly narrower than the D_2 transition of ^{85}Rb, while maintaining a high transmission into the drop port. The tunability of the filter properties presents our device as a versatile platform for selective frequency filtering with a subnatural atomic linewidth resolution.

[1] L. Masters et al, arXiv:2209.02547 (2022)

Q 42.33 Wed 16:30 Empore Lichthof

Implementation of a sub 10 ps RMS jitter TDC for Hanbury Brown Twiss measurements in Astronomy — •Verena Leopold[1], Yury Prokazov[2], Evgeny Trubin[2], Stefan Richter[1], and Joachim von Zanthier[1] — [1]FAU, Erlangen, Germany — [2]Photonscore, Magdeburg, Germany

For Hanbury Brown Twiss measurements in Astronomy, it is crucial to detect photon arrival times very precisely from multiple detectors. Usually a TDC (Time-to-Digital- Converter) is used for recording this time stream. However, for these low contrast, long-running measurements, available TDCs show disadvantages. The main challenges are low quality analog inputs and non-linearities on short ps-timescales. We succesfully implemented a TDL (Tapped-Delay-Line) TDC inside an FPGA displaying a RMS jitter of (3.24±0.03) ps with non-linearities on the order of 0.32%. As a next step the TDC will be tested in the lab before measuring a real star in Calern.

Q 42.34 Wed 16:30 Empore Lichthof

Manipulation of fluorescence emission as a tool for quantum optics experiments — •Yannick Weiser, Lorenz Panzl, Giovanni Cerchiari, and Rainer Blatt — University of Innsbruck, Technickerstraße 25, 6020 Innsbruck, Austria

We control the spontaneous emission of a trapped Ba^+ ion by back reflecting the fluorescence light of the ion onto itself via a mirror. Due to this retro reflection, the emitted photon interferes with itself, which enhances, or suppresses the emission rate, depending on the ion-mirror distance. We are working in two regimes. A static one, where the distance between the ion and the mirror is fixed and a dynamic one, where the optical path length is modulated. In both cases, applications in the field of quantum optics and quantum optomechanics are investigated.

In the static regime, we will alter the decay rate of the ion with a spherical mirror. This can suppress the fluorescence rate to 6% of its natural value. Using the spherical mirror, not only position measurements down to the quantum level are possible, but also the variance of the motional state becomes accessible. Since this scheme relies on the interaction of the fluorescence light with the emitter, no narrow internal transition is needed.

In the dynamic regime, the ion-mirror optical path will be modulated with a phase modulator. By driving the modulation with the motional frequency of the ion we can cool, or excite the ion's motion.

Q 42.35 Wed 16:30 Empore Lichthof

Second-order correlations of scattering electrons — •Florian Fleischmann[1], Mona Bukenberger[2], Raul Corrêa[3], Anton Classen[4], Simon Mährlein[1], Marc-Oliver Pleinert[1], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Department of Environmental Systems Science, ETH Zürich, 8092 Zürich, Switzerland — [3]Departamento de Física, Federal University of Minas Gerais, 31270-901 Belo Horizonte, Brazil — [4]Department of Soil and Crop Sciences, Texas A&M University, TX 77843 College Station, USA

We investigate the spatial second-order correlation function of two scattering electrons in the far field. First, we consider semi-classically the effects of the Pauli exclusion principle and Coulomb repulsion on the expected correlation pattern. This is followed by a full quantum-mechanical treatment of the problem. For this, we separate the system into center-of-mass and relative coordinates in analogy to the hydrogen atom ansatz. While the center-of-mass system is described as a free particle, we solve the Coulomb scattering problem in the relative system. We expand the respective initial state of the electrons in the eigenstates of the scattering problem. After incorporating the time evolution, the function is evaluated in the far field. We show the formal solution to the problem and discuss the current state of the numerical investigations.

Q 42.36 Wed 16:30 Empore Lichthof

Optimised single photon sources based on monolithic cavity-enhanced spontaneous parametric downconversion — •Helen Chrzanowski[1], Xavi Barcons Planas[1], and Janik Wolters[1,2] — [1]German Aerospace Center (DLR), Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany

Despite its limitations, spontaneous parametric downconversion (SPDC) remains the favoured platform for single photon generation in quantum information (QI) science. Exploiting developments in non-linear optics, recent years have ushered in increasingly sophisticated approaches to source engineering, including group velocity matching, waveguide geometries and bespoke poling techniques. Another approach of growing interest embeds the non-linear crystal within an optical cavity. Cavity-enhanced SPDC enjoys several advantages: firstly, it shifts accessible photon bandwidths from THz to GHz, enabling efficient interfacing with matter-based qubits. Such narrow spectral bandwidths also protect photon pairs from the deleterious effects of material dispersion. Secondly, the confinement of a cavity yields precise selectivity of spectral and spatial modes while also enhancing brightness - allowing high efficiencies and purities. Here, we theoretically investigate photon pair sources in resonant monolithic cavities utalising PPLN and PPKTP. We find design parameters that simultaneously optimise purity and (heralding) efficiency, while also allowing for spectral tunablity and requiring limited filtering. The development of highly pure and efficient narrowband photon pairs is a crucial tool to realise next generation of QI demonstrations.

Q 43: QI Poster II (joint session QI/Q)

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

Q 43.1 Wed 16:30 Empore Lichthof

New techniques to improve zero-noise extrapolation on superconducting qubits — •Kathrin Koenig[1,2], Thomas Wellens[1], and Finn Reinecke[1,2] — [1]Fraunhofer IAF, Freiburg, Germany — [2]University of Freiburg, Germany

Currently available quantum computing hardware suffers from errors due to environmental influences, nearest-neighbour interactions and imperfect gate operations. To achieve robust quantum computing, there are techniques like error mitigation by zero-noise extrapolation [1]. We propose a method for estimating the strength of the error occurring in a given quantum circuit in order to improve the result of this extrapolation. Furthermore, the impact of gate errors on observable expectation values can be reduced by noise tailoring, which converts arbitrary errors into stochastic Pauli errors [2]. Using these techniques, we elaborate on the implementation of error mitigation on a superconducting quantum computer and its impact on the computation of expectation values.

[1] He, A. et al., Zero-noise extrapolation for quantum-gate error mitigation with identity insertions, Phys. Rev. A 102, 012426 (2020)

[2] Wallman, J. J.; Emerson, J., Noise tailoring for scalable quantum computation via randomized compiling, Phys.Rev. A 94, 052325 (2016)

Q 43.2 Wed 16:30 Empore Lichthof

Introducing Non-Linear Activations into Quantum Generative Models — •Mykolas Sveistrys[1,2], Kaitlin Gili[2], and Chris Ballance[2] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Department of Physics, University of Oxford, Clarendon Laboratory, Parks Road, Oxford OX1 3PU, U.K.

One prominent difference between most classical generative models and current quantum ones is linearity: classical neural-network-based models require non-linear activations for quality training, while embedding such activations in quantum models is challenging due to the linearity of quantum mechanics. We introduce a quantum generative model that adds non-linear activations via a neural network structure onto the standard Born Machine framework - the Quantum Neuron Born Machine (QNBM). We utilize a previously introduced Quantum Neuron subroutine, which is a repeat-until-success circuit with mid-circuit measurements and classical control. We then compare the QNBM to the linear Quantum Circuit Born Machine (QCBM). With gradient-based training, we show that while both models can easily learn a trivial uniform probability distribution, on a more challenging class of distributions, the QNBM achieves an almost 3x smaller error rate than a QCBM with a similar number of tunable parameters. We therefore provide evidence that suggests that non-linearity is a useful resource in quantum generative models, and we put forth the QNBM as a new model with good generative performance and potential for quantum advantage.

Q 43.3 Wed 16:30 Empore Lichthof

Quantum low-precision neural networks and their classical counterparts — •Felix Soest, Konstantin Beyer, and Walter Strunz — Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany

With increasing accessibility of quantum computing devices and the successes of classical machine learning, efforts have been made to combine the two. Whether using quantum resources can provide an advantage to trainability or generalisability remains an open question, as the size of classical neural networks is much larger than what current quantum technologies can offer. Moreover, a clear indication of a quantum advantage is usually hard to identify. An often considered ansatz is that of parametrised unitaries, where the quantum machine learning model comprises multiple layers the parameters of which are trained classically. It has recently been shown that these models have classical surrogates [1], allowing for a classical benchmark to compare these models to. However, classical feed-forward neural networks can in general not be mapped to unitaries, in part due to the lack of irreversibility. Therefore we aim to construct a framework using intermediate measurements which has a classical counterpart. The resulting network is a parametrised quantum channel that allows us to reproduce classical low-precision networks as a special case. Allowing for quantum operations in this framework extends the classical regime, providing a good benchmark.

[1] Schreiber et al. arXiv:2206.11740

Q 43.4 Wed 16:30 Empore Lichthof

Learning Quantum Processes — Kerstin Beer[1], Dmytro Bondarenko[1,2], Terry Farelly[1], Younes Javanmard[1], Tobias J. Osborne[1], Debora Ramaciotti[1], Nils Renziehausen[1], Robert Salzmann[1,3], •Viktoria-Sophie Schmiesing[1], Robin Syring[1], Nils Zolitschka[1], and Ramona Wolf[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover — [2]Stewart Blusson Quantum Matter Institute, University of British Columbia — [3]Department of Applied Mathematics and Theoretical Physics, University of Cambridge

Machine learning and quantum computing are both emerging topics of research. In this poster, we tackle the issue of learning quantum processes. To do so, we use dissipative quantum neural networks.

Q 43.5 Wed 16:30 Empore Lichthof

Exact Qubit Resonance Calibration and Power Narrowing — •Ivo Mihov and Nikolay Vitanov — Department of Physics, St Kliment Ohridski University of Sofia, 5 James Bourchier blvd, 1164 Sofia, Bulgaria

At resonance, pulse shapes do not affect the population transfer; nevertheless, pulse shapes play a vital role in shaping the resonance response curves of a qubit. The response curves react differently to Rabi frequency increases, where some exhibit power broadening (e.g. rectangular pulses) but other ones do not change their width. In this work, the experimental frequency response curves of various pulse shapes were validated against theoretical predictions. Also, the effects of symmetrical truncation of Lorentzian-shaped pulses to different degrees were examined. More significantly, a solid power narrowing pattern was observed in Lorentzian pulses.

Q 43.6 Wed 16:30 Empore Lichthof

The QuMIC project - Towards a scalable ion trap with integrated high-frequency control — •Sebastian Halama[1] and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Ion traps are a promising candidate for a scalable quantum computer [1]. A major challenge is the integration of qubit control into the device. With the microwave near-field approach [2], qubit control realized by microwave conductors that are integrated into the ion trap naturally scale with the trap itself. However, the microwave signal generation currently takes place outside of the vacuum chamber in which the ion trap is located. The QuMIC project researches and develops novel highly integrated BiCMOS chips at high frequencies and their hybrid integration with quantum electronics like ion traps. This approach enables the scalability of a quantum computer to a large number of qubits and a drastic reduction in the number of required high-frequency lines, which also benefits the cooling capabilities of the cryostat used to cool down the ion trap to around 4 K. We describe the setup of a cryogenic ion trap apparatus for rapid testing of traps, such as the ion traps with integrated microwave sources developed for QuMIC. We will report on the current status of the project.

[1] Chiaverini et al., Quantum Inf Comput **5**, 419-439 (2005)

[2] Ospelkaus et al., Phys. Rev. Lett. **101**, 090502 (2008)

Q 43.7 Wed 16:30 Empore Lichthof

Tailored based composite pulses for NV-color centers towards the realization of ensembles-based quantum tokens — •Jan Thieme, Josselin Bernardoff, Ricky-Joe Plate, and Kilian Singer — Experimentalphysik I, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel

We present numerical and experimental results of the application of tailored composite pulses [1] to shape the excitation profile addressing only selected resonances of quantum states in the system. By using analytical methods applied to the Rosen-Zener excitation model [2], we derive excitation profiles for a broadband excitation profile with respect to detuning and pulse duration. Towards this goal we are using an arbitrary waveform generator to supply these pulses to single nitrogen-vacancy color centers [3]. In the outlook we will describe how this scheme is relevant for the realization of ensemble-based quantum tokens [4].

[1] B. T. Torosov and N. V. Vitanov, Phys. Rev. A 83, 053420 (2011). [2] N. Rosen and C. Zener, Phys. Rev. 40, 502 (1932). [3] A. Schmidt, J. Bernardoff, K. Singer, J. P. Reithmaier and C. Popov, Physica Status Solidi A, 216, 1900233 (2019). [4] https://www.forschung-it-sicherheit-kommunikationssysteme.de/projekte/diqtok

Q 43.8 Wed 16:30 Empore Lichthof

Quantum speed limit dependence on the number of controls in a qubit array. — •David Pohl, Fernando Gago-Encinas, and Christiane P. Koch — Arnimallee 14, 14195 Berlin

Qubit arrays form the basic unit of quantum computers. As such, it is desirable to be able to manipulate each qubit as needed. However, including a local control on every qubit is not scalable to a large number of qubits. On the other hand, reducing the number of controls might be sufficient for manipulation but slow down the implementation of quantum gates, bringing the system closer to the decoherence limit. Here, we investigate how quickly quantum gates can be implemented depending on the number of local controls. In particular, we show how the quantum speed limit (the shortest time to generate a quantum gate) increases when reducing the number of controls. We determine this limit for a universal set of gates for different 3-qubit systems using Krotov's optimization method.

Q 43.9 Wed 16:30 Empore Lichthof

Towards realizing an ultra-high vacuum chamber and experimental control of trapped ion systems using surface traps. — •Maharshi Pran Bora, Ulrich Warring, Florian Hasse, Deviprasath Palani, Phillip Kiefer, Apurba Das, Lucas Eisenhart, Tobias Spanke, and Tobias Schaetz — Physikalisches Institut, Freiburg, Albert-Ludwigs-Universität, Deutschland

Trapped ion systems are promising platforms for realizing quantum systems for quantum simulations and quantum information processing.The scalability and performance of these trapped ion systems depends crucially on the vacuum apparatus in which the trap is operated in and also on the efficiency and robustness of the experimental control of these systems. The project firstly aims at designing and characterizing an ultra-high vacuum chamber for the Phoenix surface trap produced at the Sandia National Laboratories . The Phoenix trap is a state of the art linear surface trap with high optical access. The scope of the project will include reaching an vacuum pressure of less than 10^{-9} Pa and consideration of an optimum design for the proper functioning of the trap . Secondly, to attain better experimental control, addressing of individual ions with a local beam using piezo devices will be also explored in this project . The calibration and characterization of the piezo driven platform will be reported. Hence, this project will aim at providing an improved understanding of the impact of UHV design and experimental control on the quality of operation of trapped ion systems.

Q 43.10 Wed 16:30 Empore Lichthof

Towards Quantum Control of Calcium Ions for the use in Molecular Spectroscopy — •Manika Bhardwaj, Josselin Bernardoff, Jan Thieme, Daqing Wang, and Kilian Singer — Experimentalphysik I, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel

We are building a measurement methodology for selective spectroscopy of long-lived states with a calcium ion. We want to use binary search on the $4^2S_{1/2}$-$3^2D_{5/2}$ transition of the calcium atom for the resonance search. Through the use of composite pulses techniques, we will change the narrow excitation profile with a passband pulse [1] for binary search. The final goal is to employ this method to identify the long-lived states of the lanthanoid molecular ions [2] targeting their use in molecular quantum information processing platforms.

References:

[1] B. T. Torosov, and N. V. Vitanov, Physical Review A 83, 053420 (2011).

[2] K. Groot-Berning, T. Kornher, G. Jacob, F. Stopp, S. T. Dawkins, R. Kolesov, J. Wrachtrup, K. Singer, and F. Schmidt-Kaler, Physical Review Letters 123, (2019).

Q 43.11 Wed 16:30 Empore Lichthof

Optimising gate performance of transmon qubits coupled by a central tunable bus — •Alexander Möller[1,2], Matthias G. Krauss[2], Daniel Basilewitsch[2,3], and Christiane P. Koch[2] — [1]Technische Universität Berlin, Berlin, Germany — [2]Freie Universität Berlin, Berlin, Germany — [3]Universität Innsbruck, Innsbruck, Austria

For transmon qubits coupled via a transmission line cavity, optimal control theory (OCT) has identified the quasi-dispersive regime to be optimal for universal quantum computing. For a single control driving the harmonic coupler, both local and entangling gates can be implemented with high fidelity and short gate durations [Goerz et al., *npj Quantum Information* **3**, 37 (2017)]. In an analogous manner we aim at exploring the transmon parameter landscape for a system of two transmons addressed by a third transmon acting as a tunable bus. We investigate how the anharmonicity of this central coupler affects the implemented gates and the OCT optimisation. Here we especially focus on the controllability of the two-transmon-subsystem as well as the achievable gates for different pulse durations and from this determine their respective quantum speed limit. Furthermore, we present an effective analytical model for the coupling between the outer transmons.

Q 43.12 Wed 16:30 Empore Lichthof

Single qubit gate optimization based on ORBIT cost functions — •Catharina Broocks[1,2], Max Werninghaus[1], Niklas Glaser[1,2], Federico Roy[1,3], and Stefan Filipp[1,2,4] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik Department, Technische Universität München, Garching, Germany — [3]Theoretical Physics, Saarland University, Saarbrücken, Germany — [4]Munich Center for Quantum Science and Technologies (MCQST), Munich, Germany

Analytic control solutions for qubit gates are limited by the knowledge about modeled experimental hardware properties. To achieve high-fidelity gates for superconducting qubit devices, we optimize pulse parameters of analytic solutions with respect to experimental feedback loops. As cost function the ground state population after a net-identity series of Clifford gates is used. For small parameter sets, the parameter-landscape can serve as a reference to verify numerical system models and provide insight into the sensitivity and correlation of individual parameters. To find an optimal parameter configuration, we apply simultaneous multi-parameter optimization of single-qubit gates in form of CMA-ES closed-loop optimization. We analyze the behavior of the optimization algorithm when using features such as sensitivity adjustment, influence of various noise contributions and the design of the cost function to achieve a reliable and complete convergence of the algorithm. The optimization routine can then be used to verify and address various optimal control problems, such as robustness and avoidance of leakage out of the qubit subspace.

Q 43.13 Wed 16:30 Empore Lichthof

Predicting the minimum control time of quantum protocols with artificial neural networks — •Sofia Sevitz[1], Nicolás Mirkin[1], and Diego A. Wisniacki[1,2] — [1]Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, Buenos Aires, Argentina — [2]CONICET - Universidad de Buenos Aires, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires, Argentina

Quantum control relies on the driving of quantum states without the loss of coherence, thus the leakage of quantum properties onto the environment over time is a fundamental challenge. One work-around is to implement fast protocols, hence the Minimal Control Time (MCT) is of upmost importance. Here, we employ a machine learning network in order to estimate the MCT in a state transfer protocol. An unsupervised learning approach is considered by using a combination of an autoencoder network with the k-means clustering tool. The Landau-Zener (LZ) Hamiltonian is analyzed given that it has an analytical MCT and a distinctive topology change in the control landscape when the total evolution time is either under or over the MCT. We obtain that the network is able to not only produce an estimation of the MCT but also gains an understanding of the landscape's topologies. Similar results are found for the generalized LZ Hamiltonian while limitations to our very simple architecture were encountered.

Q 43.14 Wed 16:30 Empore Lichthof

Error Budget for the Sørensen-Mølmer Gate — •Susanna Kirchhoff[1,2], Frank Wilhelm-Mauch[1,2], and Felix Motzoi[3] — [1]Institute of Quantum Computing Analytics (PGI 12), Forschungszentrum Jülich, Germany — [2]Theoretical Physics, Saarland University, Saarbrücken, Germany — [3]Institute of Quantum Control (PGI-8), Forschungszentrum Jülich, Germany

The Sørensen-Mølmer gate is an entangling gate for ion qubits, where the entanglement is achieved by a bichromatic laser beam. The gate speed and fidelity are limited by leakage to other levels. We present a detailed expression for the fidelity including higher Lamb-Dicke orders and propose methods to improve gate speed and fidelity.

Q 43.15 Wed 16:30 Empore Lichthof

Optimizing for an arbitrary Schrödinger cat state — •Matthias G. Krauss[1], Anja Metelmann[2], Daniel M. Reich[1], and Christiane P. Koch[1] — [1]Freie Universität, Berlin, Germany — [2]Karlsruhe Institute of Technology, Karlsruhe, Germany

Schrödinger cat states are non-classical superposition states that are useful in quantum information science, for example for computing or sensing. Optimal control theory provides a set of powerful tools for preparing such superposition states, for example in experiments with superconducting qubits [Ofek, et al. *Nature* **536**, 2016]. We present a set of cat state functionals which provide more freedom to the optimization algorithms, compared to state-to-state functionals. By using Krotov's method [Reich et al. *J. Chem. Phys.* **136**, 2012], we demonstrate their application by optimizing the dynamics of a Kerr-nonlinear system with two-photon driving and analyze the robustness of the cat state preparation under single and two-photon decay. In addition, we explore the generation of cat states in higher order Kerr systems. Furthermore, we show the versatility of the framework by applying it to a Jaynes-Cummings model and optimize towards arbitrary entangled cat states. We identify the strategy of the obtained control fields and determine the quantum speed limit as a function of the cat state's excitation. Finally, we extend the investigation to open quantum systems to analyze the benefit of reoptimization together with the changes in the control strategy induced by decay.

Q 43.16 Wed 16:30 Empore Lichthof

Operation of a microfabricated 2D trap array — •Marco Valentini[1], Matthias Dietl[1,2], Silke Auchter[1,2], Michael Dieter[1,2], Philip Holz[3], Clemens Rössler[2], Thomas Monz[1,3], Philipp Schindler[1], and Rainer Blatt[1,3,4] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Alpine Quantum Technologies GmbH, 6020 Innsbruck, Austria — [4]Institute for Quantum Optics and Quantum Information, 6020 Innsbruck, Austria

We investigate scalable surface ion traps for quantum simulation and quantum computing. We have developed a microfabricated surface trap consisting of two parallel contiguous linear trap arrays with 9 trapping sites each. An interconnected three-metal-layer structure provides addressing of the DC electrodes across the chip and shielding of the silicon substrate. The trap fabrication is carried out by Infineon Technologies in an industrial facility, which allows for complex electrode designs and ensures high process reproducibility. We demonstrate trapping and shuttling of multiple ions in the trap array, and form square and triangular ion-lattice configurations with up to six ions. We characterize stray electric fields and measure ion heating rates between 131(13) and 470(50) ph/s in several trapping sites. Furthermore, we engineered our setup to control independently the RF voltage in between the two linear trap arrays, and we will make use of it to demonstrate motional coupling of ions across the lattice.

Q 43.17 Wed 16:30 Empore Lichthof

Engeneering of tin vacancies in diamond by lattice charging — •Vladislav Bushmakin[1,2], Oliver von Berg[1], Santo Santonocito[1], Sreehari Jayaram[1], Petr Siyushev[1], Rainer Stöhr[1,2], Andrej Denisenko[1,2], and Jörg Wrachtrup[1,2] — [1]Universität Stuttgart, 3. Physikalisches Institut, Allmandring, 13, 70569, Stuttgart, Germany — [2]Max-Plank-Institut für Festkörperforschung Heisenbergstraße 1, 70569 Stuttgart, Germany

Recent advances in the integration of spin-bearing solid-state defects in optical cavities for efficient spin-photon entanglement are mostly associated with silicon vacancy in diamond. Meanwhile, the implantation of diamond with heavier group IV ions promises similar performance but at elevated temperatures above 1 K, which contrasts with the stringent requirement of approximately 100 mK for the coherent manipulation of the SiV electron spin. However, the generation of defects involving heavier atoms, such as tin is accompanied by a high density of defects induced by ion implantation. Here we present a method of reduction of the implantation-induced density of defects by implanting through the Boron-doped charged lattice with a subsequent etching of the damaged layer. The given method is an extension of the conventional implantation technique and hence significantly less experimentally demanding than techniques relying on CVD overgrowth or HPHT annealing. Additionally, it provides better accuracy of implantation and allows for the efficient generation of tin vacancies with a narrow inhomogeneous zero-phonon line distribution.

Q 43.18 Wed 16:30 Empore Lichthof

Robust and miniaturized Zerodur based optical and vacuum systems for quantum technology applications — •Sören Boles[1], Jean Pierre Marburger[1], Moritz Mihm[3], André Wenzlawski[1], Ortwin Hellmig[1], Klaus Sengstock[2], and Patrick Windpassinger[1] — [1]Institut für Physik, JGU, Mainz — [2]Institut für Laserphysik, UHH, Hamburg — [3]Centre for Quantum Technologies, NUS, Singapore

In the ongoing quantum revolution of science, many current studies aim to bring quantum systems to market maturity, such as quantum computers and quantum sensors. Ongoing efforts attempt to increase the accessibility of such systems, while minimizing size, mass and power requirements.

We previously demonstrated the succesful use of stable optical and laser systems based on the glass ceramic Zerodur in space borne atom interferometry experiments, e.g. FOKUS, KALEXUS and MAIUS.

On this poster, we present current developments of Zerodur to metal vacuum flanges, enabling accessible, yet mechanically and thermally stable vacuum systems. Furthermore, we report on the ongoing effort of the construction of a passively pumped Zerodur vacuum chamber for quantum sensoric applications, using optical activation of passive pumps and atom dispensers to demonstrate a MOT.

Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers 50WM2266B, 50WP1433 & 50WP2103.

Q 43.19 Wed 16:30 Empore Lichthof

Spin coherence control in an optically pumped magnetometer for space-borne magnetomyography — •Simon Nordenström[1], Victor Lebedev[1], Stefan Hartwig[1], Kirti Vardhan[2], Sascha Neinert[2,3], Jenichi Felizco[3], Martin Jutisz[2,3], Markus Krutzik[2,3], and Thomas Middelmann[1] — [1]Physikalisch-Technische Bundesanstalt, Berlin, Germany — [2]Humboldt-Universität zu Berlin, Berlin, Germany — [3]Ferdinand-Braun-Institut, Berlin, Germany

Detecting astronauts' neuromuscular degeneration with conventional methods such as surface or needle electromyography is inadequate or too detrimental. Optically pumped magnetometers (OPMs), on the other hand, allow for flexible handling and non-invasive measurements, utilizing the unique properties of alkali atom vapors interacting with external magnetic fields and laser light.

In this poster, we report on our progress in implementation of minimally necessary field control facilities to support the highest performance of the OPM, compatible with measurements on a space station. We investigate the balance between atomic spin coherence relaxation processes, anticipated dynamic range and response bandwidth in a magnetically perturbing environment. We present the anticipated system design and test results under lab conditions.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50WM2168 and 50WM2069.

Q 43.20 Wed 16:30 Empore Lichthof

Miniaturized fiber-based endoscope with direct laser written antenna structures — •Stefan Dix[1], Jonas Gutsche[1], Erik Waller[1,2], Georg von Freymann[1,2], and Artur Widera[1] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, 67663 Kaiserslautern, Germany

Fiber-based endoscopic sensors are established and widely applied as local fluorescence detectors for various samples, replacing bulky microscopes. Such sensors require the integration of sensing objects, such as nitrogen-vacancy (NV) centers in diamond and microwave antennas on small scales. Here, the microwave (MW) field addresses a transition in the NV center for magnetic field sensing. The MW fields needed are usually created using thin conducting wires or chip-based antennas close to the diamond sample. These approaches either lead to fragile, bulky, or inefficient sensor tips.

Here, we present a robust fiber-based endoscope with a direct laser written silver antenna structure close to a 50 μm multimode fiber core for optimal efficiency. Using such an endoscope, we measure an ODMR sensitivity of $17.8\,\mathrm{nT}/\sqrt{\mathrm{Hz}}$ by probing 15 μm large diamonds entirely through the endoscope. Furthermore, we demonstrate a new method for measuring distances based on measurements of the Rabi frequency.

Q 43.21 Wed 16:30 Empore Lichthof

Status and perspective of a next generation, GHz bandwidth, on-demand single-photon source — •Felix Moumtsilis[1], Max Mäusezahl[1], Moritz Seltenreich[1], Jan Reuter[2,3], Hadiseh Alaeian[4], Harald Kübler[1], Matthias Müller[2], Charles Stuart Adams[5], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Forschungszentrum Jülich GmbH, PGI-8, Germany — [3]Universität zu Köln, Germany — [4]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, USA — [5]Department of Physics, Joint Quantum Centre (JQC), Durham University, UK

The ultimate challenge of coherent experiments in thermal vapors lies in the inevitable movement of atoms that must be overcome to profit from this highly scalable and miniturizable platform e.g. for high fidelity Rydberg logic gates. GHz interaction energies and nanosecond dephasing times in a thermal rubidium vapor demand equally fast coherent control of the atomic excitations, movement, and density.

Here we report on the current state, technical challenges, and the perspective of our next generation single photon source based on the Rydberg blockade. This involves an electronic pulse shaping system with sub-nanosecond jitter, two state-of-the-art 1010 nm pulsed fiber amplifiers, an ultra narrow yet high-contrast wavelength filtering of single photons, high NA focussing, and detection. Beyond our established micrometer thick wedged cells, we investigate novel glass cell geometries requiring a whole new set of manufacturing technologies.

Q 43.22 Wed 16:30 Empore Lichthof

Magnetometry with NV centers and Waveguide-Assisted Detection Channels — •Sajedeh Shahbazi[1], Michael Hoese[1], Michael K. Koch[1,2], Vibhav Bharadwaj[1,3], Johannes Lang[1], Argyro N. Giakoumaki[3], Roberta Ramponi[3], Fedor Jelezko[1,2], Shane M. Eaton[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Ulm, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Ulm, Germany — [3]Institute for Photonics and Nanotechnologies (IFN) - CNR, Milano, 20133, Italy

The negatively charged Nitrogen-Vacancy(NV) center in diamonds has shown great success in nanoscale, high-sensitivity magnetometry. Efficient fluorescence detection is crucial for improving sensitivity and for practical sensor-integrated devices. One way to approach such a goal is using ultrafast laser writing waveguides on the diamond to create such an on-chip integrated quantum sensor. Here, we present femtosecond laser-written type II waveguides on a diamond surface, integrated with NV centers a few nanometers below the diamond surface while covering the entire mode field of waveguides [1]. We experimentally verify the coupling efficiency and the detection of magnetic resonance signals through the waveguides to perform magnetic field sensing. In the future, our approach will enable the development of two-dimensional sensing arrays facilitating spatially and temporally correlated magnetometry.

[1] M. Hoese et al., Phys. Rev. Applied 15, 054059 (2021)

Q 43.23 Wed 16:30 Empore Lichthof

Experimentation platform towards a standardized characterization of ion traps for industrial and academic users — •Hemanth Kalathur[1], André P. Kulosa[1], Erik Jansson[1], Elena Jordan[1], Jan Kiethe[1], Nicolas Spethmann[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Leibniz Universität Hannover, Hannover

Enabling technologies for quantum technologies (QT), such as ion traps, have become indispensable in the fields of quantum computing, quantum simulation, and quantum sensing. A successful commercialization of QT requires extensive knowledge exchange between research and industry.

The Quantum Technology Competence Center (QTZ) at PTB has the central goal of becoming the bridge between research and industry in Germany. The user facility "Ion Traps" of QTZ will provide a user-friendly experimentation platform for the standardized characterization of ion traps. In the long term, the performance of ion traps, e.g. ion micromotion and heating rates will be characterized. We will use incorporated automated routines to enable intuitive access to our measurement platform for collaborators even with a non-physics background. Here, we report about our experimentation platform in operation and the first comprehensive characterization of an ion trap as a cornerstone for the future standardization activities of QTZ.

Q 43.24 Wed 16:30 Empore Lichthof

Absorption sensing mode in radio frequency electrometry using Rydberg atoms in hot vapors — •Matthias Schmidt[1,2], Stephanie Bohaichuk[1], Chang Liu[1], Harald Kübler[2], and James P. Shaffer[1] — [1]Quantum Valley Idea Laboratories , 485 Wes Graham Way, Waterloo, ON N2L 6R1, Canada — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffendwaldring 57, 70569 Stuttgart

We present progress in atom-based RF E-field sensing using Rydberg atoms in hot vapors. There are two distinct strategies to detect the electric field strength of the RF wave, namely the Autler-Townes limit, where the splitting of the dressed states is proportional to the incident RF electric field strength and the amplitude regime, where we determine the electric field by measuring the difference of transmission in the presence of the RF electromagnetic field. We present theoretical calculations for the amplitude regime, using a two photon excitation scheme, that show how the scattering of the probed transition changes in the presence of the RF electromagnetic field. We find an analytical expression in the thermal limit with finite wave vector mismatch that yields an accurate approximation compared to full density matrix calculation in the strong coupling limit. Our work extends the understanding of the detection of weak RF E-fields with Rydberg-atom based RF sensors. Furthermore, we present a three photon excitation scheme, with which residual Doppler broadening is suppressed. This enables a spectral resolution comparable to the Rydberg state decay rate, the spectral bandwith limitation.

Q 43.25 Wed 16:30 Empore Lichthof

Measurement of the phase-matching function in PPKTP waveguides — •Jan-Lucas Eickmann, Florian Lütkewitte, Kai-Hong Luo, Michael Stefszky, Laura Padberg, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Single-photon sources with high purity are a prerequisite for the development of practical photonic quantum computation. Spontaneous parametric down-conversion in periodically poled potassium titanyl phosphate (PPKTP) is a promising approach to generate spectrally pure quantum light by achieving a phase-matching function perpendicular to the pump function. However, the phase-matching function varies with the condition of waveguide fabrication and the quality of periodic poling. Therefore, a precise measurement of the phase matching dependence is crucial for integrated photonic quantum source engineering. In this work, we present a method for measuring the phase-matching function in PPKTP waveguides by exploiting sum-frequency generation. Using the measured phase-matching function, we reconstruct the joint spectral intensity (JSI) for different pump fields to assure the spectral purity of the heralded photon. We observe that the phase matching results in JSI functions with a tilt of around 60°, deviating 15° from a symmetric function required for optimum pure state preparation.

Q 43.26 Wed 16:30 Empore Lichthof

Control of NV centers in nanodiamonds for sensing applications — •Dennis Lönard and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern, Erwin-Schroedinger-Str. 46, 67663 Kaiserslautern, Germany

The nitrogen-vacancy (NV) color center in diamond is an essential platform for magnetic field sensing for technical and biological applications. One major advantage is that the spin state of the NV-center can be read out optically via the fluorescence. Different spin manipulation schemes, like Ramsay or Hahn echo sequences, have been proposed to influence the interaction between the final spin state and the magnetic field that is to be measured. However, the experimentally achieved sensitivities to outer magnetic fields is still far from their theoretical limits, each measurement scheme having its own set of limitations, often due to the dephasing of the spin states of neighboring NV-centers. I will present our work to further improve the limits of sensing, spanning from technical control to the prospect of combining different methods of manipulating and sensing the NV center and exploiting their multi-level structure.

Q 43.27 Wed 16:30 Empore Lichthof

Predicting coupling efficiency of KTP waveguides and fibers by mode measurement — •Florian Lütkewitte, Jan-Lucas Eickmann, Kai Hong Luo, Michael Stefszky, Laura Padberg, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

Reliable generation of photonic quantum states is of high importance for fundamental physics and quantum networks. Due to its unique dispersion properties, spontaneous parametric downconversion (SPDC) in potassium titanyl phosphate (KTP) has gathered extensive research attention as a source of heralded single photons in the telecom range. Fiber-based devices allow for plug-and-play usage omitting time-intensive free-space coupling. Integration of SPDC sources in fiber networks can be achieved with fiber-pigtailed KTP waveguides. However, single-mode waveguides in KTP show imperfect overlap with single-mode fibers due to their asymmetry and a size-mismatch between modes. Thus, optimized mode-adapted fibers are required to obtain a plug-and-play heralded photon source in KTP. In this work, we measured the mode profile of waveguides and several tapered fibers. Comparing the mode overlap, the optimal waveguide-fiber combination has been determined with upper-bound coupling efficiency of (90±1)%, based on the mode overlap integral over their measured mode profile.

Q 43.28 Wed 16:30 Empore Lichthof

Integrated optics for scaling up the performace of ion based quantum computers — •Steffen Sauer[1,2], Carl-Frederik Grimpe[3], Anastasiia Sorokina[1,2], Guochun Du[3], Pascal Gehrmann[1,2], Tunahan Gök[6,7], Radhakant Singh[6,7], Pragya Sah[6,7], Babita Negi[7], Maxim Lipkin[6,7], Stephan Suckow[6], Elena Jordan[3], Tanja Mehlstäubler[3,4,5], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nano- und Quantenengineering, Hannover, Germany — [6]AMO GmbH, Advanced Microelectronic Center Aachen, Aachen, Germany — [7]Chair of Electronic Devices, RWTH Aachen University, Aachen, Germany

Ions trapped on chips are one of the most promising approaches for quantum computers. The approach offers the advantage of high fidelity, long coherence time and scalability. In addition, the ion physics and trap chip technology are well understood. The key component for the scalability of this quantum computers are integrated optical devices, such as waveguides to transport light or grating outcouplers to emit *m beams to the ions. In the joint project ATIQ, this approach is being pursued with the aim of realising a quantum computer with 40 qubits (ions). We present simulations of integrated optical components, their applications on chips and our characterization setups.

Q 43.29 Wed 16:30 Empore Lichthof

Towards a Micro-Integrated Optically Pumped Magnetometer for Biomagnetism in Space — •Kirti Vardhan[1], Sascha Neinert[1,2], Jenichi Felizco[2], Marc Christ[1,2], Kai Gehrke[2], Andreas Thies[2], Olaf Krüger[2], Martin Jutisz[1,2], Mustafa Gündoğan[1,2], Victor Lebedev[3], Stefan Hartwig[3], Simon Nordenström[3], Thomas Middelmann[3], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany — [3]Physikalisch-Technische Bundesanstalt, Berlin, Germany

Detecting astronauts' neuromuscular degeneration with conventional methods such as surface or needle electromyography is inadequate or too detrimental. Optically pumped magnetometers (OPMs), on the other hand, allow for flexible handling and non-invasive measurements, utilizing the unique properties of alkali atom vapors interacting with external magnetic fields and laser light.

In this poster, we report on our progress towards a miniaturised, ruggedized OPM sensor head based on in-house fabricated MEMS cells for measuring biomagnetic signals in a moderately shielded environment. To this end we compare the performance of first prototypes of a micro-integrated sensor to a functional lab-scale magnetometer setup.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50WM2168 and 50WM2169.

Q 43.30 Wed 16:30 Empore Lichthof

Additive manufacturing, micro-integration and semiconductor fabrication for compact cold atom systems — Marc Christ, •Alisa Ukhanova, Simon Kanthak, Thomas Flisgen, Conrad Zimmermann, Jörg Fricke, Olaf Brox, Andrea Knigge, Wolfgang Heinrich, and Markus Krutzik — Ferdinand-Braun-Institut (FBH), Leibniz-Institut für Höchstfrequenztechnik, Berlin

Atom-based quantum sensors allow time- and field-sensing applications with an unrivalled precision compared to their classical counterparts. While lab-based operation of cold atom-based devices is well established, a transition to mobile applications requires miniaturized subsystems with reduced complexity, high stability and low size, weight and power requirements. At FBH, we start to address the miniaturization of the sensor*s physics package towards cm-scale systems, including micro-integrated, vacuum-compatible optical systems for atom trapping and manipulation, compact, 3D-printed vacuum chambers and diffraction grating based atom sources. This poster presents an overview of our efforts towards this goal.

This work is supported by FBH and partially supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant number 50WM1949 and 50WM2070.

Q 43.31 Wed 16:30 Empore Lichthof

Fiber-coupled NV Ensembles in Microdiamond as miniaturized Magnetic Field Probes — •Jonas Homrighausen[1], Jens Pogorzelski[2], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, University of Applied Sciences, Münster, Germany — [2]Department of Electrical Engineering and Computer Science, University of Applied Sciences, Münster, Germany

NV centers in diamond are a very promising candidate for precise measurement of magnetic fields. Especially NV ensembles offer the inherent ability for threedimensional reconstruction of the magnetic field vector while being optically adressable in an optically detected magnetic resonance (ODMR) setup. We utilize these properties by coupling NV ensembles in microdiamond to optical fibers in order to create magnetic probes with high spatial resolution. This however poses challenges, amongst which the efficient delivery of microwave exciation to the fiber tip. In this poster, different methods are discussed for this particular application. We use finite element simulations to compare microwave structures and investigate the according ODMR results. Furthermore, we analyse the effect of crystal orientation with respect to locally homogeneous microwave and magnetic fields.

Q 43.32 Wed 16:30 Empore Lichthof

Towards Optically Integrated Trapped Ion Quantum Computing — •Marco Schmauser[1], Philipp Schindler[1], Thomas Monz[1], Marco Valentini[1], Clemens Rössler[2], Klemens Schüppert[2], Bernhard Lamprecht[3], and Rainer Blatt[1,4] — [1]Universität Innsbruck, Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Joanneum Research, Weiz, Austria — [4]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften

Trapped ion quantum computers are known to be large and complex experiments. One of the reasons for this is that light guidance between lasers and ions is done mainly by free-beam optics, which means that the overall system requires a lot of space and is susceptible to drifts and vibrations. The only way to make such a system compact and scalable is to increasingly integrate functionality, in this specific case optical elements, from external components directly into the ion trap. To solve this problem, a method has been developed to write single-mode and polarization-maintaining waveguides directly into quartz glass using ultrashort laser pulses. These light guides can be tuned to a specific wavelength, ranging from UV to near infrared. The next step is to realize an ion trap with such integrated waveguides. In this context, the approach of a microstructured trap is pursued, which allows for a scalable trap architecture and is compatible with industrial production. In parallel, an integrated cryogenic quantum computing system is being built to enable fast trap changes and additionally investigate the light delivery to the trap chip.

Q 43.33 Wed 16:30 Empore Lichthof

Quantum memory in noble-gas nuclear spins with alkali metal vapour as optical interface — •Norman Vincenz Ewald[1], Tianhao Liu[2], Luisa Esguerra[1,3], Ilja Gerhardt[4], and Janik Wolters[1,3] — [1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin — [2]Physikalisch-Technische Bundesanstalt, FB 8.2 Biosignale, Berlin — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin — [4]Leibniz University Hannover, Institute of Solid State Physics, Light and Matter Group, Hannover

Quantum memories with storage times well beyond 1 s will spawn manifold applications in quantum communication and information processing, e.g. as quantum token for secure authentication. We present our first steps towards a quantum memory with long storage time in a mixture of the noble gas ^{129}Xe and an alkali metal vapour of ^{133}Cs. A custom glass cell at about room temperature contains both species and is placed inside a table-top magnetic shield. Information will be stored in the collective excitation of nuclear spins of ^{129}Xe, which exhibit hours-long coherence times [1]. ^{133}Cs serves as optical interface for signal photons, which we store in a collective spin excitation using EIT [2]. Coherent information transfer to the noble gas spins is based on spin-exchange collisions and will be controlled by synchronisation of Larmor precession [3].

[1] C. Gemmel et al., *Eur. Phys. J. D* **57**, 303–320 (2010).
[2] L. Esguerra et al., arXiv:2203.06151 (2022).
[3] O. Katz et al., *Phys. Rev. A* **105**, 042606 (2022).

Q 43.34 Wed 16:30 Empore Lichthof

Rack-mounted Laser Systems for Quantum Computing with Be^+ and Ca^+ Ions — •Gunnar Langfahl-Klabes[1], Niels Kurz[2], Malte Stoepper[1,2], Stephan Hannig[1], and Piet Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Institute of Quantum Optics, Leibniz University Hannover

Co-locating quantum processing units based on ion traps with classical computers in data centers requires highly integrated, transportable, modularized, turn-key laser systems in an overall form factor that complies with 19-inch rack-mount standards.

The ion trap-based quantum computer of Quantum Valley Lower Saxony (QVLS-Q1) uses Be^+ ions as qubits and Ca^+ ions for sympathetic cooling. Within three half-height server racks we provide all of the necessary lasers for cooling, repumping, and detection. Our systems feature four monolithic rack drawers that contain customized setups for sum-frequency generation, second-harmonic generation, and frequency shifting. All rack-mounted laser outputs are fiber-coupled. Free-space components for ablation and photoionization are placed close to the vacuum chamber.

The wavelengths used in our setup range from deep-UV to near-IR (235, 313, 375, 397, 422, 470, 515, 626, 854, 866, 1051, 1552 nm). With red light at 626 nm we realize a laser stabilization setup via Doppler-free iodine spectroscopy for the Be^+ cooling and detection laser system at 313 nm.

We report on the current status of our laser systems.

Q 43.35 Wed 16:30 Empore Lichthof

Towards coherent single praseodymium ion quantum memories in optical fiber microcavities — •Sören Bieling[1], Nicholas Jobbitt[1], Roman Kolesov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Universität Stuttgart, 70569 Stuttgart, Germany

Rare earth ions doped into solids show exceptional quantum coherence in their ground-state hyperfine levels. These spin states can be efficiently addressed and controlled via optical transitions and are thus ideally suited to serve as quantum memories and nodes of quantum networks. However, while long storage times, high storage efficiencies and storage on the single photon level have all been demonstrated separately, they could not yet be achieved simultaneously. We aim to demonstrate both long and efficient single quantum storage in the ground-state hyperfine levels of single Pr^{3+} ions doped into yttrium orthosilicate (YSO) by integrating them as a membrane into optical high-finesse fiber-based Fabry-Pérot microcavities. This allows for efficient addressing and detection of individual ions. We report on the design, commissioning and initial characterization of a next-gen cryogenic scanning microcavity as well as on its experimental integration into and design of a self-built vector magnet. It allows for future coherence prolongation by operating under a zero first-order Zeeman (ZEFOZ) shift magnetic field alongside dynamical decoupling sequences. Together with the Purcell enhanced emission and ultrapure Pr^{3+}:YSO membranes this strives to realize efficient and coherent spin-photon interfaces suitable for deployment in scalable quantum networks.

Q 43.36 Wed 16:30 Empore Lichthof

Towards the implementation of microwave near-field entangling gates in a cryogenic surface-electrode ion trap apparatus — •Niklas Orlowski[1], Chloë Allen Ede[1], Niels Kurz[1], Sebastian Halama[1], Timko Dubielzieg[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, 38116 Braunschweig, Germany

We discuss ion loading using different lasers for the ablation, ionization, cooling and detection of Beryllium ions and describe measures taken to isolate ions from environmental influences, for example by using vibrational decoupling, electromagnetic shielding, and an XUHV-environment [1]. We demonstrate hyperfine state preparation and manipulation with microwave pulses and discuss requirements on radial mode stability for the implementation of entangling microwave quantum gates [2].

[1] Dubielzig et al. RSI 92.4 (2021): 043201
[2] Zarantonello et al. PRL 123, 260503

Q 43.37 Wed 16:30 Empore Lichthof

Synthesis of depth confined nitrogen vacancy centers in diamond — •Karolina Schüle[1], Christoph Findler[1,2], Johannes Lang[1,2], and Fedor Jelezko[1,3] — [1]Institute for Quantum Optics, Ulm University, Ulm, Germany — [2]Diatope GmbH, Ummendorf, Germany — [3]Center for Integrated Quantum Science and Technology (IQST), Ulm, Germany

The negatively charged nitrogen-vacancy center (NV) is a paramagnetic defect (S=1) in diamond which shows coherence times T2 up to milliseconds even at room temperature. The NV is a promising candidate for quantum applications as its spin state can be initialized, read out optically, and manipulated by a microwave field. One way to fabricate NV centers is ion implantation where nitrogen is added into a single crystal diamond layer followed by an annealing process. The depth of the implanted nitrogen can be adjusted by the implantation energy. Larger kinetic energies are leading to deeper NV centers. At the same time, however, the depth distribution gets also broader limiting the degree of depth confinement. This contradicts the goal of homogeneous properties of the NVs beneficial for e.g. NMR applications. Using the method of indirect overgrowth, where implanted nitrogen is buried below a nanometer-thin capping layer of diamond. The resulting depth of the NV centers is decoupled from the implantation ion energy. Here, we show outstanding depth confinement resulting in single NVs which are located at a depth of around 20 nm confined in a range of approx. 1.4 nm. These NV centers are exhibiting a T2 up to ~100 μs.

Q 43.38 Wed 16:30 Empore Lichthof

Industrially microfabricated ion traps for quantum information processing — •Schey Simon[1,2], Pfeifer Michael Dieter Josef[1,3], Glantschnig Max[1,4], Anmasser Fabian[1,3], Abu Zahra Mohammad[1], Auchter Silke[1,3], Brandl Matthias[1], Schüppert Klemens[1], Colombe Yves[1], and Rössler Clemens[1] — [1]Infineon Technologies Austria AG, Villach, Austria — [2]Stockholm University, Stockholm, Sweden — [3]University of Innsbruck, Austria — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Infineon Technologies is fabricating 2D and 3D ion trap chips in its industrial facilities [1,2]. This poster gives an overview of our work towards large-scale, reliable ion traps.

We are developing multiple fabrication processes on silicon and dielectric substrates for, e.g., multi-metal stacks with low resistance at cryogenic temperatures, and surfaces resilient to UV laser beam exposure, which we characterize using analytical tools (cryogenic probe station, KPFM microscopy). Together with partners, we design and produce ion traps with integrated optical waveguides, and traps for ion shuttling with ~200 electrodes, that will be operated with a custom cryo-compatible electronic chip. We present a second-generation ion trap socket that allows fast exchange of traps, which we use in our ion trapping lab and make available to our partners.

[1] Ph. Holz, S. Auchter et al., Adv. Quantum Technol. 3, 2000031 (2020)
[2] S. Auchter, C. Axline at al., Quantum Sci. Technol. 7, 035015 (2022)

Q 43.39 Wed 16:30 Empore Lichthof

Characterization of single-photon emitters in hexagonal boron nitride at room temperature — •Leonora Meier[1], Pablo Tieben[2], Stefan Kück[1], Andreas Schell[2], and Marco López[1] — [1]PTB, Braunschweig, Deutschland — [2]Leibniz Universität, Hannover, Deutschland

In this work we present a study on point defects of hexagonal boron nitride (hBN) which exhibit high brightness and narrow band single photon properties. So far, several samples containing hBN defects with different concentrations have been fabricated and characterized. The characterization is performed in terms of their spectrum, single-photon purity (g(2)(0)) and stability.

It has been observed that different emitters with hBN defects exhibit different spectra, even though the single-photon purity of g(2)(0) is less than 0.3. The single-photon emission stability remains a challenge. Blinking and bleaching were observed even though the time period of stability differs greatly between different emitters.

To improve the stability of the single-photon emission, different annealing procedures will be applied; for example, heating the sample to 500°C. In addition, the variation of photoluminescence as a function of an in-plane magnetic field will be studied to determine whether hBN point defects can be used as a magnetic sensor.

Q 43.40 Wed 16:30 Empore Lichthof

Near Field Modeling for Quantum Gate Operation — •Axel Hoffmann[1], Florian Ungerechts[2], Rodrigo Munoz[2], Brigitte Kaune[2], Teresa Meiners[2], Christian Ospelkaus[2,3], and Dirk Manteuffel[1] — [1]Institut für Hochfrequenztechnik, Hannover, Leibniz Universität Hannover — [2]Institut für Quantenoptik, Hannover, Leibniz Universität Hannober — [3]PTB Braunschweig, Braunschweig

Surface-electrode ion traps with integrated microwave conductors for near-field quantum control are a promising approach for scaleable quantum computers. The goal of the QVLS-Q1 Project is to realize a scaleable quantum computer based on surface-electrode ion traps. Realizing quantum gate operations with magnetic near-field control comes with high demands on the electromagnetic field design, regarding spatial field distribution and radiation efficiency. Typically the wave length of the gate frequency is much larger than the entire application. Therefore common criteria to design efficient radiating structures can not be applied in a straight forward way. Additionally the spatial distribution, especially the position of the field minimum, is constrained to match specific requirements. These challenges will be discussed in this poster, emphasizing on the possibilities to face the complex goal of minimizing gate errors. A systematic approach will be shown including advanced simulation approaches.

Q 43.41 Wed 16:30 Empore Lichthof

Single Photon Sources at Telecom Wavelengths — •Jonas Grammel[1], Julian Maisch[2], Nam Tran[2], Thomas Herzog[2], Simone Luca Portalupi[2], Peter Michler[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart

Semiconductor single photon sources are fundamental building blocks for quantum information applications. The current limitations of such quantum dot sources are the emitting wavelength and insufficient collection efficiency in fiber-based implementations. In the project *Telecom Single Photon Sources* we aim to realize high brightness, fiber coupled sources of single and indistinguishable photons at the telecom wavelength for the upcoming realization of fiber-based quantum networks. We employ open cavities realized with fiber-based mirrors, in combination with InGaAs quantum dots emitting in the telecom O-band and C-band. To achieve Fourier-limited photons we utilize the lifetime reduction of the emitters via the Purcell effect. We optimize the mode matching between the cavity mode and the guided fiber mode by introducing a fiber-integrated mode-matching optics that can basically reach near-unity collection efficiency.

Q 43.42 Wed 16:30 Empore Lichthof

Packaging and Microfabrication Technology for Scalable Trapped Ion Quantum Computer — •Nila Krishnakumar[1,2,3], Friederike Giebel[1,2,3], Eike Iseke[1,2,3], Konstantin Thronberens[1,2,3], Jacob Stupp[1,2,3], Amado Bautista-Salvador[1,2,3], and Christian Ospelkaus[1,2,3] — [1]PTB, Bundesallee 100, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]LNQE, Schneiderberg 39, 30167 Hannover

Ion traps are a leading platform for scalable quantum computing. A physical implementation is based on microfabricated surface-electrode ion traps. A multilayer fabrication method [1] allows geometries which are impossible in single-layer traps. Thick and planarized dielectric-metal layers provide flexibility and better signal routing. The multilayer method requires microfabrication techniques such as UV Photolithography, Reactive Ion Etching(RIE), electroplating and more. Improving the efficiency and yield of the fabrication flow involves testing and updating each technology.

For scalability and hybrid integration of different control techniques, we discuss the implementation of TSVs (Through substrate vias) and better packaging technologies such as flip-chip bonding. As an alternative to the conventional wire bonding which limits the packaging density, a solder free thermocompression method proposed in [2] using gold stud bumps for flip-chip bonding is studied.

[1] A. Bautista-Salvador et al., New J. Phys. 21, 043011, Patent DE 10 2018 111 220 (2019)

[2] M. Usui et al.,(ICEP-IAAC) pp. 660-665 (2015)

Q 43.43 Wed 16:30 Empore Lichthof

Multi-Output Quantum Pulse Gate: a High-Dimensional Temporal-Mode Decoder — •Laura Serino, Jano Gil-Lopez, Michael Stefszky, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Future quantum technologies will require the implementation of complex quantum communication (QC) networks. Temporal modes (TMs) provide an appealing high-dimensional encoding alphabet based on the time-frequency degree of freedom of photons, leading to important advantages for QC applications. A TM-based QC scheme requires the simultaneous detection of multiple TMs of single photons, which has not yet been achieved.

In this work, we demonstrate high-dimensional single-photon TM decoding with a multi-output quantum pulse gate (mQPG). The mQPG is a device that provides simultaneous projection of multiple TMs onto all the elements of a chosen alphabet (or their superpositions) and maps each result onto a different output frequency. We demonstrate that the mQPG is compatible with single-photon-level input states from a full set of five-dimensional mutually unbiased bases, and we characterize its performance through a detector tomography. We then proceed to demonstrate a proof-of-principle decoder for high-dimensional quantum key distribution based on the mQPG.

Q 43.44 Wed 16:30 Empore Lichthof

Two Stage Quantum Frequency Conversion of SnV-Resonant Photons to the Telecom C-Band — •David Lindler, Tobias Bauer, Marlon Schäfer, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

Tin-Vacancy-Centers (SnV) in diamond are a promising candidate for Quantum Nodes in quantum communication networks that store and distribute quantum information [1,2]. Transferring the spin state of the SnV-Center onto single photons enables the exchange of information between these nodes over long distances through optical fiber links. The photons are converted into the low-loss telecom bands via quantum frequency down-conversion, to avoid the problem of high loss in fibers for SnV-resonant photons at 619 nm.

We here present a two-stage scheme for quantum frequency conversion of SnV-resonant photons to the telecom C-band based on difference frequency generation in PPLN waveguides. The two step process $619\,\text{nm} - 2061\,\text{nm} = 885\,\text{nm}$, $885\,\text{nm} - 2061\,\text{nm} = 1550\,\text{nm}$ drastically reduces noise at the target wavelength compared to the single stage process $619\,\text{nm} - 1030.5\,\text{nm} = 1550\,\text{nm}$, due to pumping in the long wavelength regime. We will present the characterization of key components as well as first results on conversion efficiency and conversion induced noise count rates.

[1] J. Görlitz et al., npj Quant.Inf. 8, 45 (2022).
[2] R. Debroux et al., Phys. Rev. X 11, 041041 (2021).

Q 43.45 Wed 16:30 Empore Lichthof

Entangled Photon Pair Source based on Photonic Chips with Spontaneous Four-Wave-Mixing and Pulsed PDH-Locking — •Maximilian Mengler, Erik Fitzke, Jakob Kaltwasser, and Thomas Walther — TU Darmstadt, Institute for Applied Physics, 64289 Darmstadt

For many applications, such as quantum key distribution (QKD), entangled photon pairs are desirable. We use the process of spontaneous four-wave-mixing to create such pairs in microring resonators on silicon nitride photonic chips. Results in terms of, for example, pair generation rate and coincidental-over-accidental ratio obtained from two distinct chips with different setups, specifications and waveguide geometries will be presented and compared. As the chips are intended as sources for our QKD-System, which is based on time-bins, the PDH-technique used for the locking of the microring resonators to the pump light was adapted to work with pulsed light.

Q 43.46 Wed 16:30 Empore Lichthof

Cavity-enhanced fluorescence of ensemble NV centers — •Kerim Köster[1], Maximilian Pallmann[1], Rainer Stöhr[2], Julia Heupel[3], Cyril Popov[3], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institute für Technologie (KIT) — [2]3. Physikalisches Institut, University of Stuttgart — [3]Institute of Nanostructure Technologies and Analytics (INA), Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel

Building a long-distance quantum network is one of the big challenges in the field of quantum communication, which requires the development of a quantum repeater. A crucial component of this device is an efficient, coherent spin-photon interface. Coupling color centers in diamond to a microcavity is a promising approach therefore.

In our experiment, we integrate a diamond membrane into an open access fiber-based Fabry-Perot microcavity to attain emission enhancement in a single well-collectable mode. We observe cavity-enhanced fluorescence spectra of an ensemble of shallow-implanted nitrogen vacancy centers in diamond and report a significant Purcell-enhancement of the zero-phonon line (ZPL). Furthermore, the emission yields temporal bunching of ZPL photons, which indicates a collective behavior in the emission process that can be attributed to superfluorescence.

Q 43.47 Wed 16:30 Empore Lichthof

The Twente-Münster high-speed quantum key distribution link — •Niklas Humberg[1], Alejandro Sánchez-Postigo[1], Daan Stellinga[2], Pepijn Pinkse[2], and Carsten Schuck[1] — [1]Departement for Quantum Technology, Münster, Germany — [2]University of Twente, Enschede, Netherlands

To build a pan-European network for quantum communication, many local nodes are needed to provide every city with access to quantum-secure encryption. One such link between local nodes is being developed between the University of Twente (UT) and the Westfälische Wilhelms-Universität Münster (WWU), to open a secure communication channel between the Netherlands and Germany. High-speed generation of quantum keys over the roughly 85km long dark fiber will be achieved by using wavelength division multiplexing into several frequency channels that operate in parallel. The qubit preparation and detection will be done using silicon nitride-on-insulator photonic integrated circuits. The receiver chip will integrate an interferometer with a 150 ps low-loss delay line in one arm for time bin encoding and an arrayed waveguide grating (AWG) for demultiplexing the wavelength channels. Each AWG output channel will be equipped with an efficient and low-noise superconducting nanowire single-photon detector, which have timing accuracies that are significantly better than the optical delay in the interferometer. We show progress on the chip design and the fabrication of detector devices.

Q 43.48 Wed 16:30 Empore Lichthof

Photon emission from a segmented ion-trap – cavity system: simulation and implementation — •Stephan Kucera, Max Bergerhoff, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Atom-photon interfaces [1,2] are basic requirements for quantum networks with single trapped ions. The efficiency of such interfaces has been shown to increase significantly by the use of resonators [3]. Following this direction, we are developing a new segmented ion trap for $^{40}Ca^{+}$ ions with an integrated fiber cavity [4,5] envisaging the implementation of a high-rate and high-purity quantum repeater cell (QR-cell) according to [6,7] on the basis of single-photon emission.

[1] C. Kurz et al., Nat. Commun. 5, 5527 (2014)
[2] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[3] M. Meraner et al., Phys. Rev. A 102, 052614 (2020)
[4] H. Takahashi et al., New J. Phys. 15, 053011 (2013)
[5] B. Brandstätter et al., AIP 84, 123104 (2013)
[6] D. Luong et al., Appl. Phys. B 122, 96 (2016)
[7] V. Krutyanskiy et al. arXiv preprint arXiv:2210.05418 (2022)

Q 43.49 Wed 16:30 Empore Lichthof

Polarisation-independent Conversion of single photons from infrared to ultraviolet — •Alireza Aghababaei — Nußallee 12, 53115 Bonn

Wavelength conversion at the single-photon level is required to forge a quantum network from distinct quantum devices. Such devices could include solid-state emitters of single or entangled photons, as well as network nodes based on atoms or ions. We convert single photons emitted from an III-V semiconductor quantum dot at 853nm via sum frequency conversion to the wavelength of the strong transition of Yb ions at 370nm. In this poster, we will present a sagnac setup that allows polarization-independent frequency conversion.

Q 43.50 Wed 16:30 Empore Lichthof

Polarization stabilization of an urban telecom fiber link — •Jonas Meiers, Christian Haen, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Many quantum network designs rely on glass fibers to transmit quantum information encoded into the polarization of photons [1]. Long glass fiber links, especially those deployed outside a laboratory environment are exposed to environmental influences that change the birefringence of the fiber and, as a result, the polarization of transmitted light [2], degrading the polarization-encoded information.

Here, we present the polarization stabilization of a 14 km long urban fiber link running through Saarbrücken, by utilizing lasers as polarization reference and a Gradient-Descent algorithm for error correction. This stabilization provides the necessary transmission process fidelity for quantum communication experiments, which we demonstrate by high-fidelity entanglement distribution with photon pair sources, or by quantum repeater operations.

[1] S. Neumann et al., Nat. Commun. 13, 6134 (2022)
[2] O. Karlsson et al., Journal of Lightwave Technology, 18 (2000)

Q 43.51 Wed 16:30 Empore Lichthof

Observation of quantum Zeno effects for localized spins — •Vitalie Nedelea — Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany

One of the main dephasing mechanisms for the localized carrier spins in semiconductors is the coupling to the fluctuating nuclear spin environment. Here we present an experimental observation on the effects of the quantum back action under pulsed optical measurements of spin ensemble and demonstrate that the nuclei-induced spin relaxation can be influenced. We show that the fast measurements freeze the spin dynamics and increase the effective spin relaxation time, the so-called quantum Zeno effect. Furthermore, we demonstrate that if the measurement rate is comparable with the spin precession frequency in the effective magnetic field, the spin relaxation rate increases and becomes faster than in the absence of the measurements, an effect known as the quantum antiZeno effect. A theory describing both regimes allows us to extract the system parameters and the strength of the quantum back action.

Q 43.52 Wed 16:30 Empore Lichthof

Quantum Computation and Simulation with Neutral Alkaline-Earth-like Ytterbium Rydberg Atoms in Optical Tweezers — •Nejira Pintul[1], Tobias Petersen[1], Benjamin Abeln[1], Marcel Diem[1], Oscar Murzewitz[1], Koen Sponselee[1], Christoph Becker[1,2], and Klaus Sengstock[1,2] — [1]Zentrum für optische Quantentechnologien, Universität Hamburg, Deutschland — [2]Institut für Laserphysik, Universität Hamburg, Deutschland

Experiments with neutral cold atoms trapped in reconfigurable optical tweezer arrays have recently developed into one of today's leading platforms for quantum simulation and computation, due to the innate scalability, single atom control and Rydberg blockade mechanism for generating two-atom entangling gates. However, to achieve fault-tolerant quantum computing, current atomic life- and coherence times still need improvement to increase fidelities in preparation, gate operation and read-out. Here we present our pathway in constructing an optical tweezer experiment utilizing the alkaline-earth-like atom ^{171}Yb. This isotope offers a multitude of viable advantages for encoding novel high-fidelity qubit and error correction architectures, such as the presence of a highly coherent metastable state, a two valence-electron structure with an optically active ion core and single-photon Rydberg transitions. Main milestones include the characterization of two microscope objectives, the design of magnetic coils along with electric field compensation, the development of homogeneous 2D tweezer holograms and mobile dipole traps for efficient array initialization.

Q 43.53 Wed 16:30 Empore Lichthof

Polarization-preserving quantum frequency conversion for entanglement distribution in trapped-atom based urban area quantum networks — •Tobias Bauer and Christoph Becher

— Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

In quantum communication networks information is stored in internal states of quantum nodes, which can be realized e.g. in trapped ions like 40Ca+ [1]. By transferring the states onto flying quantum bits, i.e. photons, it is possible to exchange information between these nodes over long distances via optical fiber links. In order to minimize attenuation in fibers, which is particularly high for typical transition frequencies of trapped ions, quantum frequency down-conversion of the transmitted photons to low-loss telecom bands is utilized [2].

We present a high-efficiency, rack-integrated quantum frequency converter for polarization-preserving conversion of 40Ca+-resonant photons to the telecom C-band. This converter is highly suited for real-world application in entanglement distribution experiments in urban area fiber networks, e.g. photonic entanglement [3] or creation of remote entanglement of atomic systems.

[1] C. Kurz et al., Phys. Rev. A. 93, 062348 (2016)
[2] M. Bock, P. Eich et al., Nat. Commun. 9, 1998 (2018)
[3] E. Arenskötter, T. Bauer et al., arXiv:2211.08841

Q 43.54 Wed 16:30 Empore Lichthof

high sensitivity magnetometry with NV centers in diamond at zero field — •Muhib Omar, Arne Wickenbrock, Dmitry Budker, Georgios Chatzidrosos, Till Lenz, Omkar Dungel, and Joseph Rebeirro — Helmholtz Institut Mainz, Deutschland

We investigate a magnetometric protocol for sensing weak ac magnetic fields inside magnetic shieldings using ensembles of Nitrogen-Vacancy (NV) centres in diamond. The aim is to utilise this sensor for zero to ultra low field NMR detection, promising improved Signal-to-Noise ratio by the smaller standoff distance to a NMR sample this type of magnetometer would allow compared to standard optically pumped magnetometers. We present a scheme to enhance photon collection to improve so called shot noise limited sensitivity of magnetic field detection of this sensor type and a scheme that would allow measuring weak ac fields stroboscopically without being limited by effects dominating at very low fields like strain and NV-NV dipolar coupling.

Q 43.55 Wed 16:30 Empore Lichthof

Compact and portable atomic vapor memory for single photon storage — •Alexander Erl[1,2,3], Leon Messner[3,2], Martin Jutisz[3], Luisa Esguerra[2,1], Elizabeth Robertson[2,1], Norman Vinzenz Ewald[2], Elisa Da Ros[3], Mustafa Gündoğan[3], Markus Krutzik[3,4], and Janik Wolters[2,1] — [1]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Berlin, Germany — [3]Humboldt-Universität zu Berlin, Institut für Physik, Berlin, Germany — [4]Ferdinand-Braun-Institut, Institut für Höchstfrequenztechnik, Berlin, Germany

Quantum memories for single photons are a key component of quantum repeaters for sattelite-based quantum communication over long distances [1,2]. Memories on sattelites for feasible quantum repeater networks must be compact, maintainable and scalable. Reliable storage and retrieval of photons on demand would make a significant contribution to memory assisted quantum key distribution.

We present a compact, rack-mounted, stand-alone warm vapor quantum memory based on electromagnetically induced transparency (EIT) on the Cs D1 line at 895 nm [3]. This mobile setup realizes high fidelity light storage at single photon level with minimal readout noise level.

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)
[2] N. Sangouard et. al., arXiv:0906.2699 (2009)
[3] L. Esguera, et al., arXiv:2203.06151 (2022)

Q 43.56 Wed 16:30 Empore Lichthof

Quantum network with interacting network qubits — •Emanuele Distante, Severin Daiss, Stefan Langenfeld, Stephan Welte, Philip Thomas, Lukas Hartung, Olivier Morin, and Gerhard Rempe — Max Planck Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Quantum networks can be realized out of single atoms trapped at the centre of optical resonators which stand at the network nodes and are then connected via optical fibres. In this platform, quantum information is stored into the long-lived ground states of an atom, and the resonator provide an efficient way to entangle the atomic states with flying optical photons. Traveling over the network via the fibres, photons can not only distribute the entanglement over large distance but also provide a means for making two largely separated atoms interact. In this poster we will show how this effective long-distance interaction can be exploited for the realization of different protocols. First, we present a quantum logic gate between distant atoms[1], which denote a rudimental example of distributed quantum computation, then we show the realization of a novel quantum teleportation scheme[2], as well as realization of joint nondestructive measurement on distant qubits leading to entanglement[3].

[1] S. Daiss *et al.*, Science **371**, 614-617 (2021)
[2] S. Langenfeld *et al.*, Phys. Rev. Lett. **126**, 130502 (2021)
[3] S. Welte *et al.*, Nat. Phot. **15**, 504-509 (2021)

Q 43.57 Wed 16:30 Empore Lichthof

Measuring the temporal mode function of photonic states — •Olivier Morin, Stefan Langenfeld, Matthias Körber, Philip Thomas, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Quantum physics, and quantum information in particular, relies on the accurate control of the quantum states. For optical states, while some well-establish techniques exist for the characterization of polarization and spatial degrees of freedom, it remains a non-trivial task to measure the temporal mode function of a photonic quantum state. Here we present an easy-to-implement and accurate solution [1]. Our method is based on homodyne measurements. We show that the proper processing of the auto-correlation function can give access to any complex-valued temporal mode function. Beyond the theoretical principle, we also consider the experimental constraints and provide the key aspects to obtain a trustworthy reconstruction. We have tested our method on an advanced temporal shape and reach a fidelity as high as 99.4%. This technique has also been used to characterize the complex-valued temporal shape of a single photon emitted from a CQED system. Hence, we believe that this method can be applied to many other systems and become a standard routine in quantum optics laboratories.

[1] O. Morin *et al.*, Phys. Rev. A **101**, 013801 (2020)

Q 43.58 Wed 16:30 Empore Lichthof

Characterization of Polarization Drifts on a Deployed Inter-City Fiber Link for Quantum Communication — •Pritom Paul[1,2], Gregor Sauer[2,1], Shreya Gouravaram Navalur[2,1], and Fabian Steinlechner[2,1] — [1]Institute of Applied Physics, Friedrich Schiller University Jena, Albert-Einstein-Straße 15, 07745 Jena, Germany. — [2]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Straße 7, 07745, Germany.

Quantum communication involves the transmission of quantum information between two or more distant nodes in a network by encoding it, for example into the polarization state of photons. Such photons can be transmitted to distant nodes via free space or fiber-based links. In our experiment, we use a fiber link to transmit such photons.

The state of polarization of light changes with propagation along an optical fiber. These changes are irregular over time and occur due to perturbations from the environment such as temperature fluctuations throughout the day as well as the actual movement of the fibers. In the end, one must compensate for these polarization changes in order to effectively readout the quantum correlations in the polarization degree of freedom[1]. In this work, we want to understand the different aspects of these polarization changes on a 150km deployed fiber link between Jena and Erfurt in order to develop and improve our existing polarization compensation techniques. We report on the current status of the project.

[1] C.Z. Peng, et.al, Phys. Rev. Lett. 98, 010505(2007).

Q 43.59 Wed 16:30 Empore Lichthof

Towards optical tweezer arrays for cavity based quantum information processing — •Matthias Seubert, Lukas Hartung, Stephan Welte, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

In recent decades, single neutral atoms in a strongly coupled optical resonator have developed to a powerful tool for quantum information processing and network application [1]. Increasing the number of individually controllable atoms in this platform provides the possibility to increase the efficiency of existing protocols by multiplexing, and additionally opens the way towards novel information processing and network protocols. However, this requires precise control of the atom position within the cavity mode which is a challenging demand.

Here, we show the implementation of a tweezer setup, capable of positioning atoms within an optical cavity, using a 2D acousto-optic deflector. ^{87}Rb atoms are first loaded at the center of the cavity, then transferred into optical tweezers and finally repositioned at sub-wavelength precision. In this manner, tweezer arrays allow one to load a deterministic number of atoms and to move individual atoms from a strongly coupled to a non-coupled position. In the future, this setup offers the possibility to address individual atoms, detect or rotate their state and generate single atom-photon entanglement.

[1] A. Reiserer and G. Rempe, Rev. Mod. Phys. 87, 1379 (2015)

Q 43.60 Wed 16:30 Empore Lichthof

A quantum frequency converter for the connection of Rb atoms in a cavity over long distances — •Maya Büki, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institute für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Rubidium atoms in a cavity are a promising platform for realizing long-distance quantum networks as the atomic ground states can be efficiently entangled with optical photons [1]. However, photons entangled with Rb atoms are typically at a wavelength ($\lambda_{\mathrm{Rb}} = 780\,\mathrm{nm}$) which is unfavourable for long-distance communication due to intrinsic fiber losses in this regime. To efficiently transport the quantum information encoded in optical polarisation qubits over long distances, a wavelength conversion to the telecom regime ($\lambda = 1460 - 1565\,\mathrm{nm}$) is necessary.

Here, we demonstrate such a polarisation conserving quantum frequency converter (QFC) in a Sagnac configuration [2] and investigate the possibilities of increasing the signal-to-noise ratio (SNR) by choosing a suitable final wavelength. Provided a good SNR and high fidelities, the QFC represents one of the many necessary building blocks to establish a long distance quantum network. Furthermore, it can be used to connect diverse platforms operating at different wavelengths, thus forming a hybrid quantum network which takes advantage of the specific capability of each system.

[1] A. Reiserer, G. Rempe, Rev. Mod. Phys. **87**, 1379 (2015).
[2] R. Ikuta *et al.*, Nat. Commun. **9**, 1997 (2018).

Q 43.61 Wed 16:30 Empore Lichthof

Transport waveforms for through-junction ion transport on surface-electrode ion traps for a QCCD architecture — •Rodrigo Munoz[1], Florian Ungerechts[1], Axel Hoffmann[1,2], Brigitte Kaune[1], Teresa Meiners[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Register-based ion traps are among the leading approaches for scalable quantum processors. These are defined by the spatial division of different operations such as storage, state preparation and readout. A fundamental characteristic of the register-based approach is the translation of ions to reach the different registers of the QCCD architecture. Here, we discuss registers interconnected through a x-junction. We will focus on the necessary through-junction transport.

We will present the different constraints applied to our optimization algorithm in order to obtain trapping potentials for different ion species. Besides, we will also discuss additional conditions that allow a reliable trough-junction transport.

Q 43.62 Wed 16:30 Empore Lichthof

A Quantum Network Node with Crossed Fiber Cavities — •Tobias Frank[1], Gianvito Chiarella[1], Pau Farrera[1], Manuel Brekenfeld[1], Joseph Christesen[1,2], and Gerhard Rempe[1] — [1]MPQ, Hans-Kopfermann-Str. 1, 85748Garching, Germany — [2]NIST, Boulder, Colorado 80305, USA

Recent development in the field of optical cavity QED mainly concern a further reduction of the mode volumes of the resonators, driven by the development of fiber-based Fabry-Perot cavities (FFPCs) [1], and an increase in the number of well-controlled modes the emitters can couple to. We implemented an experiment which combines these two experimental advancements in a single platform consisting of single neutral atoms trapped at the center of two crossed FFPCs. Exploiting the possibilities provided by this platform, we have realized a quantum network node that couples to two spatially and spectrally distinct quantum channels. The node functions as a passive heralded quantum memory [2], achieving a heralded average state fidelity of $94.7 \pm 0.2\,\%$ and neither requires amplitude- or phase-critical control fields [3] nor error-prone feedback loops [4]. Our platform is therefore excellently suited for the realization of future large-scale quantum networks and quantum repeaters.

[1] Hunger et al., New J. Phys. 12, 065038 (2010)
[2] Brekenfeld et al., Nature 591, 570 (2020)
[3] Specht et al., Nature 473, 190 (2011)
[4] Kalb et al., Phys. Rev. Lett. 114, 220501 (2015)

Q 43.63 Wed 16:30 Empore Lichthof

Nondestructive detection of photonic qubits — •Pau Farrera, Dominik Niemietz, Stefan Langenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Garching, Germany

Qubits encoded in single photons are very useful to distribute quantum information over remote locations, but at the same time are also very fragile objects. The loss of photonic qubits (through absorption, diffraction or scattering) is actually the main limitation in the maximum reachable quantum communication distance. In this context, the nondestructive detection of photonic qubits is a great scientific challenge that can help tracking the qubit transmission and mitigate the loss problem. We recently implemented such a detector [1] with a single atom coupled to two crossed fiber-based optical resonators, one for qubit-insensitive atom-photon coupling and the other for atomic-state detection. We achieve a nondestructive detection efficiency of 79(3)% conditioned on the survival of the photonic qubit, a photon survival probability of 31(1)%, and we preserve the qubit information with a fidelity of 96.2(0.3)%. To illustrate the potential of our detector we show that it can provide an advantage for long-distance entanglement and quantum-state distribution, resource optimization via qubit amplification, and detection-loophole-free Bell tests.

[1] D. Niemietz et al., Nature 591, 570-574 (2021)

Q 43.64 Wed 16:30 Empore Lichthof

Towards a compact polarization entanglement source based on WGMR — •Sheng-Hsuan Huang[1,2], Thomas Dirmeier[1,2], Golnoush Shafiee[1,2], Alexander Otterpohl[1,2], Florian Sedlmeir[1,2], Dmitry Strekalov[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91108, USA

Crystalline Whispering Gallery Mode Resonators (WGMR) made from nonlinear materials have been proven to be compact and efficient sources of quantum states, e.g. squeezed states [1] or narrow-band heralded single photons[2,3]. Another feature of WGMR is, that it is possible to couple two pump beams propagating in opposite directions at the same time. As a result, we can treat the WGMR similar to a Sagnac interferometer which is simultaneously a pair of two independent and indistinguishable SPDC sources. Combined, these features make WGMR a potential platform for developing compact and narrow-band entanglement sources.

In our presentation, we discuss the concept and progress of developing a compact polarization entanglement source based on a WGMR that is pumped from two directions.

[1]A. Otterpohl, et.al., Optica 6, 1375-1380 (2019)
[2]J. U. Fürst, et al., Physical review letters 104.15 153901 (2010)
[2]M. Förtsch, et al., Physical Review A 91(2) 023812 (2015)

Q 43.65 Wed 16:30 Empore Lichthof

Apparatus design for scalable cryogenic trapped-ion quantum computing experiments — •Lukas Kilzer, Tobias Pootz, Celeste Torkzaban, Timko Dubielzig, and Christian Ospelkaus — Institute of Quantum Optics, Leibniz University Hannover

Further progress in trapped-ion quantum computing requires a dramatic increase in the number of ion qubits that can interact with each other. We describe the design of cryogenic demonstrator machines for this task, focusing on the implementation of surface-electrode ion traps. Trap design and implementation is facilitated through the use of a universal interchangeable socket. The apparatus design is based on a vibration isolated cold head to cool a cryogenic vacuum system to temperatures around 5K. The apparatus features a high density of DC control lines to support transport of qubits through complex processor structures including junctions, dedicated storage, detection and manipulation registers. Multi-qubit quantum gates can be implemented through the use of chip-integrated microwave methods. Two setups are currently under construction, the first being based on $^{9}\mathrm{Be}^{+}$ qubits and $^{40}\mathrm{Ca}^{+}$ ions for sympathetic cooling; the second setup will be based on $^{43}\mathrm{Ca}^{+}$ qubits and $^{88}\mathrm{Sr}^{+}$ cooling ions. The first setup will benefit from our experience with the $^9Be^+$ qubit, whereas the second setup with longer wavelengths for cooling and detection will be amenable for integrated chip-integrated photonics. The system has been designed to accommodate the integration of new components for scaling as the development of the underlying enabling technologies progresses.

Q 44: Integrated Photonics II (joint session Q/QI)

Time: Wednesday 17:00–19:00 Location: A320

Q 44.1 Wed 17:00 A320

Integrated bright broadband PDC source for quantum metrology — •René Pollmann, Franz Roeder, Victor Quiring, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Broadband quantum light is a vital resource for quantum metrology applications such as quantum spectroscopy, quantum optical coherence tomography or entangled two photon absorption. For entangled two photon absorption especially very high brightness combined with high spectro temporal entanglement is crucial to observe a signal. So far these conditions could be met by using high power lasers driving bulk degenerate type 0 spontaneous parametric down conversion (SPDC) sources. This naturally limits the available wavelength ranges and precludes deterministic control over the output state. In this work we show an integrated two colour SPDC source utilising a group-velocity matched lithium niobate waveguide, reaching both high brightness ($> 6.7 \cdot 10^{11}$ pairs/Ws) and large bandwidth (> 6 THz) while using less than 5 mW of continuous wave pump power. Since the product of the measured correlation time of the photons $\Delta\tau \approx 80$ fs and the pump bandwidth of $\Delta\omega_p \ll 1$ MHz violates the classical Fourier limit, the source shows very strong time frequency entanglement. Furthermore our process can be adapted to a wide range of central wavelengths.

Q 44.2 Wed 17:15 A320

Diced ridge waveguides in titanium indiffused lithium niobate — •Michelle Kirsch, Christian Kiessler, Christof Eigner, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Lithium niobate (LN) is a widely used platform for integrated optical devices due to its optical properties, especially the high second order nonlinearity. Well-established titanium indiffused waveguides (Ti:LN) are limited in the ability of creating tightly confined fields due to the low index contrast. Another limitation in Ti:LN waveguide devices is the occurrence of intensity induced photorefractive damage inhibiting applications with high optical intensities in the waveguides. To counteract these challenges we use a ridge waveguide structure to achieve higher confinement in horizontal direction by precision diamond blade dicing in Ti:LN. We analysed the properties of the guided modes in dependence of the waveguide geometry for 1550 nm. Furthermore, we fabricated periodically poled ridge waveguides and characterized the second harmonic generation process by measuring the phase matching function at a pump wavelength of 1550 nm and the efficiency. Here we show an efficiency of $9.44\,\%\mathrm{W}^{-1}\mathrm{cm}^{-2}$. Moreover, we investigated the occurrence of photorefractive damage in the ridge waveguides by measuring the second harmonic power in dependence of the pump power. Here we show a high damage resistance up to a pump power of 500 mW.

Q 44.3 Wed 17:30 A320

Waveguide-Intergrated Superconducting Nanowire Avalanche Single-Photon Detectors — •Connor A. Graham-Scott[1,2,3], Matthias Häussler[1,2,3], Mikhail Yu. Mikhailov[4], and Carsten Schuck[1,2,3] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]Center for Soft Nanoscience (SoN), Busso-Peus-Straße 10, 48149 Münster, Germany — [4]B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, 61103 Kharkiv, Ukraine

Superconducting nanowire single-photon detectors (SNSPDs) are of great interest for applications in quantum communication, quantum information and quantum computing. A drawback of SNSPDs, however, is the low signal-to-noise ratio of their electrical output signals, resulting from operating at bias currents below the critical current of the ultra-thin superconducting nanowires.

High signal-to-noise ratio can be achieved by implementing a superconducting nanowire avalanche single photon detector (SNAP) architecture that connects several SNSPD elements in parallel, thus realising operation at high bias current and successive switching of elements upon photon absorption and current redistribution.

Here we show the design, fabrication and measurements of a successive-avalanche architecture SNAP with amorphous molybdenum silicide nanowires integrated with nanophotonic waveguides for on-chip single-photon counting with ultra-high signal-to-noise ratios.

Q 44.4 Wed 17:45 A320

Lithium-niobate microcombs for dual-comb spectroscopy — •Stephan Amann[1], Bingxin Xu[1], Yang He[2], Theodor W. Hänsch[1,3], Qiang Lin[2], Kerry Vahala[4], and Nathalie Picque[1] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Department of Electrical and Computer Engineering, University of Rochester, Rochester, New York 14627, USA — [3]Faculty of Physics, Ludwig-Maximilian University of Munich, Munich, Germany — [4]T.J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, California 91125, USA

On-chip optical microresonators with a high Q-factor can generate soliton microcombs, broad spectra consisting of narrow lines with equal linespacing corresponding to the free spectral range of the resonator. Thin-film lithium niobate is a promising platform due to its large transparency window, strong second- and third-order nonlinearity and electro-optic effect. Here by driving a high-Q thin-film lithium niobate resonator with a picosecond electro-optic comb at 1.5 micron, we report stable soliton generation at a repetition rate locked by the electro-optic comb. Its high peak power grants an oscillation threshold at lower average powers than those necessary with continuous-wave pumping. The microcombs with a line spacing of 100GHz are well suited for spectroscopy in the condensed matter, where the linewidths of absorption features are often of the order of several hundreds of GHz. Dual-comb spectroscopy will leverage the time-domain interference of two microcombs to measure broad spectra within short measurement times.

Q 44.5 Wed 18:00 A320

Design of a satellite-based single photon source for quantum communication — •Najme Ahmadi for the QUICK3-Collaboration — Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany

Technologies of the so-called second quantum revolution have matured such they can now be used in space applications, e.g., long-distance quantum communication. Here we present the design of a compact true single photon source that can enhance the secure data rates in satellite-based quantum key distribution scenarios compared to conventional laser-based light sources. Our quantum light source is based on a fluorescent color center in hexagonal boron nitride. The emitter is off-resonantly excited by a diode laser and coupled to an integrated optics circuit that routes the photons to different experiments. These experiments either characterize the source directly by the second-order correlation function or test extended physical theories beyond the standard model. Our payload is currently being integrated into a 3U CubeSat and scheduled for launch in 2024 into the low Earth orbit. We can therefore evaluate the feasibility of true single photon sources in space and provide a promising route toward a high-speed quantum internet.

Q 44.6 Wed 18:15 A320

Influence of doping on the optical characteristics in lithium niobate — •Laura Bollmers, Laura Padberg, Christof Eigner, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Lithium niobate (LN) is a well-established material in integrated optics, and it is commonly used in nonlinear photonics. To make LN

more versatile, material doping is crucial in improving the device's applicability. Depending on the doping material and concentration, different applications can be realised, e.g. Titanium doping can be used for waveguide fabrication, an essential part of integrated optics. Zinc doping can shift a bandgap to the UV region, enabling the material for UV/VIS application. Erbium doping enables applications for optical amplification, used for integrated laser sources, or quantum optical applications like memories.
Thus, doping LN can lead to a performance boost for optical applications. Especially in thin-film lithium niobate there are completely new application possibilities for doped substrate material. For optimisation, the interplay of experimental analysis and theoretical material modelling is crucial. So, we investigate the absorption spectra influenced by different dopants at different temperatures and show our latest results.

Q 44.7 Wed 18:30 A320

Towards Reconfigurable Lithium-Niobate-on-Insulator integrated non-von Neumann processors — •Julian Rasmus Bankwitz[1,2], Seongmin Jo[2], Francesco Lenzini[1], and Wolfram Pernice[2] — [1]Institute of Physics, University of Münster, Germany — [2]Kirchhoff Institute for Physics, University of Heidelberg, Germany

In recent years Artificial neural networks (ANNs) showed great advantages in a variety of fields like autonomous driving or language recognition. Fast and efficient efficient matrix-vector-multiplications (MVMs) are the building blocks of ANNs, as they represent the mathematical description of the interconnects of the ANN's neurons. With the exponentially increasing amount of data the world is generating every year, classical von-Neumann structured computers are facing their limits in computation speed and energy consumption. Overcoming those boundaries is a crucial task for modern computing, giving rise to alternative platforms like photonic integrated circuits (PICs). Lithium-Niobate-on-Insulator (LNOI) is an emerging material platform due to its broad optical bandwidth, low propagation loss and high second-order nonlinearity, enabling small footprint electro-optically reconfigurable circuits like adjustable ring resonators for non-classical light sources and Mach-Zehnder-Interferometers (MZIs) for electrically tunable optical switches. Here we demonstrate novel approaches of optical ANN matrices utilizing MZIs from LNOI for ultra-fast MVMs. From high precision fabrication engineering and modular PIC design we show high MZI extinction rations above 24 dB combined with GHz range modulation speed.

Q 44.8 Wed 18:45 A320

Light manipulation via integrated focusing grating couplers for quantum computing applications — •Anastasiia Sorokina[1,2], Guochun Du[3], Pascal Gehrmann[1,2], Carl-Frederik Grimpe[3], Steffen Sauer[1,2], Elena Jordan[3], Tanja Mehlstäubler[3,4,5], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nanound Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

Downsizing optical components to control ion species in quantum computation is a vital turning point. Integrating routing and focusing elements into the chip architecture can substantially suppress environmental distortions and boost scalability. We investigated integrated waveguides and grating couplers to produce a linearly polarised Gaussian beam with a predefined emission angle, focus height and the size of the beam at this position. The studies were carried out using Lumerical FDTD simulation software and a subsequent post-processing routine. To address the different wavelengths required for the entire operation of the ion-based QCs, we have evaluated the capabilities and performance of our structures by taking advantage of the two most promising material platforms: Si_3N_4 and AlN. Our results can help overcome current limitations toward the multi-ion quantum system.

Q 45: Photonics III

Time: Thursday 11:00–13:00 Location: A320

Q 45.1 Thu 11:00 A320

Probing nonlinear optical processes with free electrons — •Jan-Wilke Henke[1,2], Yujia Yang[3,4], F. Jasmin Kappert[1,2], Arslan S. Raja[3,4], Germaine Arend[1,2], Guanhao Huang[3,4], Armin Feist[1,2], Zheru Qiu[3,4], Rui Ning Wang[3,4], Aleksandr Tusnin[3,4], Alexey Tikan[3,4], Tobias J. Kippenberg[3,4], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Germany — [3]Institute of Physics, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland — [4]Center for Quantum Science and Engineering, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland

Integrated photonics has proven to facilitate the interaction of light with free electrons in electron microscopy by significantly boosting the coupling strength. This enables the exploration of quantum optics with free electrons as well as a probing of nonlinear optical effects inherent to integrated microresonators with electron spectroscopy.

Here, we harness the inelastic electron-light scattering to investigate the spatial and spectral properties of the electric field inside a high-Q silicon nitride microresonator. For increasing optical input powers, characteristic changes to the electron energy spectra that coincide with the formation of various nonlinear intracavity states including dissipative Kerr solitons are observed.

In the future, this enables new schemes in electron beam modulation and manipulation, while electron-based optical state probing may also be extended to different quantum states of light.

Q 45.2 Thu 11:15 A320

Incoherent diffractive imaging of (non)regular structures — •Sebastian Karl[1], Stefan Richter[1], Manuel Bojer[1], Fabian Trost[2], Kartik Ayyer[3], Henry Chapman[2], Ralf Röhlsberger[4], and Joachim von Zanthier[1] — [1]QOQI, FAU Erlangen Nürnberg, Germany — [2]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [3]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [4]Helmholtz-Institut Jena, Germany

X-ray crystallography relies on coherent scattering for high resolution structure determination. However, often the predominant scattering mechanism is an incoherent process like fluorescence, introducing severe background in the coherent diffractogram. Incoherent diffractive imaging (IDI) aims to use this incoherently scattered light for structure determination by measuring second order correlations in the far field [1]. While in theory single shot 3d imaging would be possible using IDI, careful theoretical examinations place thresholds on its feasibility [2,3]. IDI has been implemented at the European XFEL using metal foils. After evaluations for regular structures have been performed [4], we discuss the evaluation progress for non-regular structures and comment on the possibility of ab initio phasing using third order correlations on this dataset [5].

[1] A. Classen et al, PRL 119, 053401, 2017 [2] F. Trost et al., New J. Phys. 22, 083070, 2020 [3] L. M. Lohse et al., Acta Cryst. A 77, 480-496, 2021 [4] F. Trost et al., to be published [5] N. Peard et al., arXiv:2210.03793

Q 45.3 Thu 11:30 A320

Optical Ramsey Spectroscopy on a Single Organic Molecule — •Yijun Wang[1], Vladislav Bushmakin[2], Guilherme Stein[2], Andreas Schell[1,3], and Ilja Gerhardt[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany — [2]3. Physikalisches Institut, Universität Stuttgart and Stuttgart Research Center of Photonic Engineering (SCoPE), Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [3]Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany

Single molecules are important players in quantum optics. Their coherence is of uttermost importance, since it influences the usage in quantum information processing, such as in quantum networking applications. We implement a pump-probe experiment in a Ramsey-type pulse sequence on a single 2.3,8.9-dibenzanthanthrene (DBATT) molecule to measure the optical coherence time and compare it with conventional methods [1]. The molecule is selected microscopically and spectroscopically at T=1.4 K. We also perform frequency-detuned excitation, gaining richer insights into the dephasing behavior of the molecule. The experiments exhibit that optical Ramsey spectroscopy is a promising tool for measuring the emitter's coherence properties.

[1] – Y. Wang, V. Bushmakin, G. Stein, A. Schell, and I. Gerhardt, *Optical Ramsey spectroscopy on a single molecule,* Optica **9**, 374-378 (2022).

Q 45.4 Thu 11:45 A320

Photoacoustic spectroscopy with a tunable narrowband infrared laser system — •Luca Schmid, Florent Kadriu, Sandro Kuppel, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

We report on a photoacoustic setup with a narrowband picosecond ultrafast tunable laser system in the mid-infrared. The fingerprints of various atmospheric species such as humid ambient air and carbon dioxide overtones at $5000\,\mathrm{cm}^{-1}$ at 2000 ppm have been detected. The entire molecular overtone is scanned within a few seconds with a linewidth-limited resolution of $2\,\mathrm{cm}^{-1}$. We quantify the signal-to-noise ratio and compare these data with theoretically calculated spectra from the HITRAN database. Even extremely weak resonances can be resolved owing to the excellent brilliance of the laser source with several hundreds of mW output power.

Q 45.5 Thu 12:00 A320

Thermodynamic control of stimulated Brillouin-Mandelstam scattering in liquid-core optical fiber — •Andreas Geilen[1,2], Alexandra Popp[1,2], Debayan Das[1,3], Saher Junaid[4,5], Christopher G. Poulton[6], Mario Chemnitz[7], Christoph Marquardt[1,2], Markus A. Schmidt[4,5], and Birgit Stiller[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, 91058 Erlangen, Germany — [3]Université Bourgogne Franche-Comté, 25030 Besançon, France — [4]Leibniz Institute of Photonic Technology, 07745 Jena, Germany — [5]Otto Schott Institute of Materials Research, 07743 Jena, Germany — [6]School of Mathematical and Physical Sciences, University of Technology, Sydney, NSW 2007, Australia — [7]Centre Énergie Matériaux Télécommunications, Québec, J3X 1S2, Canada

We present temperature and pressure dependent Brillouin-Mandelstam scattering measurements inside a fully sealed, CS_2-filled liquid-core optical fiber. The confinement of the liquid inside the micrometer-size silica capillary allows us to control and investigate the thermodynamic behavior. Tuning the temperature from 5 °C to 135 °C we reach high pressure values above 1000 bar as well as substantial absolute negative pressure values below -300 bar. With this, the Brillouin frequency shift (BFS) can be tuned by 40%. Our platform offers a rich source for fundamental optoacoustic investigation of liquids in different thermodynamic states, maintaining all-fiber convenience, while the low BFS (≈2.5 GHz) and a high temperature sensitivity of 7 MHz/°C are promising for sensing applications.

Q 45.6 Thu 12:15 A320

Optical solitons in curved spacetime — Felix Spengler[1], •Alessio Belenchia[1,2], Dennis Rätzel[3,4], and Daniel Braun[1] — [1]Institut für Theoretische Physik, Eberhard-Karls-Universität Tübingen, 72076 Tübingen, Germany — [2]Centre for Theoretical Atomic, Molecular, and Optical Physics, School of Mathematics and Physics, Queens University, Belfast BT7 1NN, United Kingdom — [3]ZARM, University of Bremen, Am Fallturm 2, 28359 Bremen, Germany — [4]Humboldt Universität zu Berlin, Institut für Physik, Newtonstraße 15, 12489 Berlin, Germany

From the seminal work of Plebanski in the '60s, we know that Maxwell equations in vacuum curved spacetime are equivalent to flat-spacetime Maxwell equations in the presence of a bi-anisotropic moving medium whose dielectric permittivity and magnetic permeability are determined entirely by the space-time metric. We will use this insight in order to describe light propagation in a non-linear stationary medium in curved spacetime. We will focus on the case of a weak gravitational field and, via a non-linear Schrödinger equation, describe the propagation of an optical pulse in an effective, gradient-index medium in flat spacetime, which encodes both the material properties and curved spacetime effects. Furthermore, in analyzing the special case of propagation in a 1D optical fiber, we will also include the effect of mechanical deformations and show it to be the dominant effect for a fiber oriented in the radial direction in Schwarzschild spacetime.

Q 45.7 Thu 12:30 A320

Optical control of one-dimensional topological end states via soliton formation — •Christina Jörg[1,2], Marius Jürgensen[2], Sebabrata Mukherjee[3], and Mikael C. Rechtsman[2] — [1]Physics Department and Research Center OPTIMAS, TU Kaiserslautern, D-67663 Kaiserslautern, Germany — [2]Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA — [3]Department of Physics, Indian Institute of Science, Bangalore 560012, India

Solitons are solutions of the nonlinear Schrödinger equation that maintain their shape during propagation. Here we show that soliton formation can be used to optically induce and control a linear topological end state in the bulk of a Su-Schrieffer-Heeger (SSH) lattice, using evanescently-coupled waveguide arrays. We observe an abrupt nonlinearly-induced transition above a certain power threshold due to an inversion symmetry-breaking nonlinear bifurcation of the soliton. We use a pump-probe framework such that the dynamics of the soliton is only coupled to the end state via the potential it induces, meaning that we may control the end state independently and all-optically. Specifically, we use orthogonal polarizations for the pump and probe: The pump induces the soliton and the probe experiences the potential induced by the soliton in which an end state appears as a result. In our case, the soliton acts as an all-optical switch to turn on and off the topological (linear) end state. Our results demonstrate all-optical active control of topological states.

Q 45.8 Thu 12:45 A320

From Berry phase to quantum skyrmions: a geometric loop tour in Physics — •Sinuhe Perea — Strand King's College London

In several physics systems the whole can be obtained as an exact copy of each of its parts, which facilitates the study of a complex system by looking carefully at its elements, separately. Reducionism offers simplified models which makes the problems easier, but "there's plenty of room...at the \emph{mesoscopic} scale". Here we present a tour for two of its representants: Berry phase and skyrmions, studying some of its basic definitions and properties, and two cases in which both arise together, to finish constraining the scale for our mesoscopic system in the quest of quantum skyrmions, discovering which properties are conserved and which others may be destroyed. In several classical physics systems the whole can be obtained as an exact copy of each of its parts, which facilitates the study of a complex system by looking carefully at its elements, separately. Reductionism offers simplified models which makes the problems easier, but "there's plenty of room...at the discrete scale". Here we present a tour for two of its representants: Constant section fiber bundles and skyrmions, studying some of its basic definitions and properties, and an example where both arise together via domain wall analogy. We will finish constraining the scale for our mesoscopic system in the quest of quantum and photonic skyrmions from above via Hamiltonian local minimisation and for below via novel graphic re-writing evolution, discovering which properties are conserved and which others may be destroyed.

Q 46: Quantum Control (joint session QI/Q)

Time: Thursday 11:00–13:00 Location: B305

Invited Talk Q 46.1 Thu 11:00 B305

Quantum firmware: optimal control for quantum simulators — •Tommaso Calarco — Forschungszentrum Jülich, 52428 Jülich, Deutschland — Universität zu Köln, 50937 Köln, Deutschland

Quantum optimal control has been shown to improve the performance of quantum technology devices up to their limits in terms e.g. of system size and speed of operation. This talk will review our recent results with a variety of quantum technology platforms, focusing in particular on ultracold atoms, and introduce our newly developed software for automatic calibration of quantum operations - the fundamental building block of next-generation quantum firmware.

Q 46.2 Thu 11:30 B305

Optimal Control in the Chopped Random Basis — •Matthias Müller — Forschungszentrum Jülich GmbH

We are at the verge of the second quantum revolution where quantum technology leaves the lab and enters industrial products. Fragile quantum systems with their unique features like superposition and entanglement can offer new perspectives in computation, communication and sensing/metrology. However, they need sophisticated mechanisms of control to perform the desired tasks. Quantum Optimal Control has proven to be a powerful tool to accomplish this task. I will report on the optimization in the dressed chopped random basis (dCRAB) [1], a versatile and robust approach to Quantum Optimal Control, that allows both closed-loop and open-loop optimization with limited pulse bandwidth and guaranteed convergence in a broad range of typical applications. The interplay of constraints, control resources and noise [2,3] is crucial for the overall performance of the controlled operation which obeys fundamental bounds that can be found also in full quantum control [4].

[1] M.M. Müller et al., Rep. Prog. Phys. 85 076001 (2022) [2] S. Lloyd et al., PRL 113, 010502 (2014) [3] M.M. Müller et al., arxiv:2006.16113 (2020) [4] S. Gherardini et al., Phys. Rev. Research 4 (2), 023027 (2022)

Q 46.3 Thu 11:45 B305

Graph test for controllability of qubit arrays — •Fernando Gago-Encinas, Monika Leibscher, and Christiane P. Koch — Freie Universität Berlin, Arnimallee 14, 14195 Berlin

Universal quantum computing requires evolution-operator controllability of the system used as quantum processing unit. Given a specific architecture characterized by the two-qubit couplings and local controls it uses, we seek to determine whether it is controllable or not. The standard test constructing the dynamical Lie algebra becomes demanding and even unfeasible already for a relatively small number of qubits. We present a controllability test for arrays of coupled qubits based on graph theory that significantly broadens the number of cases that can be analyzed. We showcase the algorithm for different examples, including some systems based on IBM's devices.

Q 46.4 Thu 12:00 B305

Optimal Control of Bipartite Entanglement with Local Unitary Control — •Emanuel Malvetti — Department of Chemistry, Technische Universität München, Lichtenbergstr. 4, 85737 Garching, Germany — Munich Centre for Quantum Science and Technology & Munich Quantum Valley, Schellingstr. 4, 80799 München, Germany

A pure quantum state on a bipartite system can always be transformed into a diagonal form using local unitary transformations. This is the well-known Schmidt decomposition. Here we consider a closed bipartite system with local unitary control. The Schmidt decomposition allows us to define a reduced control system on the Schmidt values, which is equivalent to the original control system. We will explicitly describe this reduced control system and study its properties. In particular, we will treat the case of rank one drift Hamiltonians and some low dimensional cases in detail.

Q 46.5 Thu 12:15 B305

Taking Markovian Quantum Dynamics to Thermal Limits: Principles, Practice, and Perspectives — •Thomas Schulte-Herbrüggen[1,2], Frederik vom Ende[1,2], Emanuel Malvetti[1,2], and Gunther Dirr[3] — [1]Technical University of Munich (TUM) — [2]Munich Centre for Quantum Science and Technology (MCQST) and Munich Quantum Valley (MQV) — [3]Institute of Mathematics, Universität Würzburg

To begin with, consider the following engineering problem: Which quantum states can be reached by coherently controlling n-level quantum systems coupled to a thermal bath in a switchable Markovian way? We address this question by giving (inclusions for) reachable sets of coherently controllable open quantum systems with switchable coupling to a thermal bath of temperature T as an additional resource.

A core problem reduces to the dynamics of the eigenvalues of the density operator. It translates into a toy model of studying points in the standard simplex allowing for two types of controls: (i) permutations within the simplex, (ii) contractions by a dissipative semigroup. We show how toy-model solutions pertain to the reachable set of the original controlled Markovian quantum system. Beyond the case $T = 0$ (amplitude damping) we present results for $0 < T < \infty$ by using recent methods of extreme points of the d-majorisation polytope.

We give illustrating examples, experimental applications, and perspectives at the intersection of control theory with resource theory.

Refs.: Proc. MTNS (2022), 1069 and 1073

Q 46.6 Thu 12:30 B305

Tailoring feedback control loops to work best where it matters the most — •Robin Oswald — ETH Zürich

Experiments in AMO physics rely on many feedback control loops stabilizing quantities such as temperatures, magnetic fields and laser phase, frequency and intensity. In most cases, PID controllers are used for these tasks, but they only allow for coarse adjustment of the relevant trade-offs. Here, I will present methods to augment and tailor control loops to be particularly effective in one or several narrow frequency bands, i.e. where there are particularly strong disturbances or where the apparatus is especially vulnerable to them, or both. Using examples from our trapped-ion laboratory I will illustrate how we can leverage these techniques to improve the performance of the feedback loops, and ultimately our experiments.

Q 46.7 Thu 12:45 B305

Unitary Interpolation — •Michael Schilling, Matthias Müller, and Felix Motzoi — Forschungszentrum Jülich, Jülich, Deutschland

The generation of matrix exponentials and associated differentials, required to determine the time evolution of quantum systems, is frequently the primary source of running time in quantum control problems. We introduce two ideas for the time efficient approximation of matrix exponentials of linear parametric Hamiltonians. We modify the Trotter and Suzuki-Trotter product formulas from approximation to interpolation schemes to improve their accuracy. To achieve our target fidelities within a single interpolation step and avoid the need of exponentiation, we furthermore define the interpolation on a grid of interpolation intervals. We demonstrate a speed up of at least an order of magnitude when compared with eigenvalue decomposition, Runge-Kutta and Suzuki-Trotter based approaches. This holds true independent of system dimension, for problems with few time dependent controls.

Q 47: Precision Measurements with Optical Clocks (joint session Q/QI)

Time: Thursday 11:00–13:00 Location: E001

Invited Talk Q 47.1 Thu 11:00 E001

Quantum metrology with non-classical states of light — •Michèle Heurs — Institute for Gravitational Physics, Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

Nowadays, non-classical (fixed-quadrature "squeezed") light is routinely used in second-generation interferometric gravitational wave detectors such as aLIGO and AdVirgo to increase their detection sensitivity, leading to some of the most exciting astrophysical discoveries of the past years. Beyond this well-known application example, squeezing is a quantum technique that can benefit precision metrology in many other areas. It can be useful whenever the signal-to-noise ratio of the measurement is fundamentally limited by the quantum noise of the employed and technically already ultra-stabilised laser light.

This talk will highlight exemplary applications of squeezed light, ranging from interferometric gravitational wave detection to sub-shot-noise limited spectroscopy. The latter example makes use of high-frequency squeezed light sources, so-called *squeezing combs*, which will be introduced in this talk. These squeezing combs exhibit entanglement between the individual upper and lower squeezing sidebands which occur at the free spectral ranges of the squeezing cavity. This feature makes squeezing combs a promising resource for applications in quantum information.

Q 47.2 Thu 11:30 E001

A strontium optical clock based on Ramsey-Bordé spectroscopy — •Amir Mahdian[1], Oliver Fartmann[1], Ingmari C

Tietje[1], Martin Jutisz[1], Conrad L Zimmermann[2], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We are developing an optical frequency reference based on Ramsey-Bordé interferometry using a thermal atomic beam. The $5s^2\ ^1S_0 \rightarrow 5s5p\ ^3P_1$ intercombination line in strontium is chosen as our clock transition, which should allow for an Allan deviation as low as 2×10^{-15} between 100 s and 1000 s.

After an overview of the current state of our atom interferometer, the latest developments in our laser systems and frequency stabilization will be presented. Moreover, I outline two methods for reading the population of the associated quantum states in the clock transition, along with the progress on spectroscopy on the $5s5p\ ^3P_1 \rightarrow 5p^2\ ^3P_0$ line at 483 nm.

This work is supported by the German Space Agency (DLR), with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant number DLR50WM1852, and by the German Federal Ministry of Education and Research within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 47.3 Thu 11:45 E001

Instability investigation for a dual-wavelength coating frequency stabilization cavity — •Fabian Dawel[1,2], Alexander Wilzewski[1,2], Johannes Kramer[1,2], Lennart Pelzer[1,2], Marek Hild[1,2], Kai Dietze[1,2], Gayatri Sasidharan[1,2], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Optical resonators are a key tool for stabilizing lasers. For many experiments space is limited, so it is advantageous to lock multiple lasers to the same resonator. But so far, the correlation in noise contributions for two or more lasers on the same mirror pair has not been investigated. In this talk we present the stabilization of two lasers operating at 729 nm and 1069 nm on one mirror pair. We measure the effect of photo-thermal noise (PTN) and residual-amplitude modulation (RAM) on laser frequency instability. We find correlations between optical power and frequency. The wavelength coating stack next to the substrate shows PTN noise which is suppressed by coherent cancelation to a level of $3 \times 10^{-8}\ \frac{\mathrm{Hz}}{\mathrm{W}}$. The stack on top of this shows a PTN of $7 \times 10^{-7}\ \frac{\mathrm{Hz}}{\mathrm{W}}$. As expected, there is no significant cross-correlation between the lasers for noise induced by RAM. We measured relative frequency instabilities of less than 10^{-14} for both lasers, where the instability of one laser is limited by RAM. This work shows that dual-wavelength coatings can be used for highly stable laser applications, which makes it a viable tool for precision spectroscopy experiments.

Q 47.4 Thu 12:00 E001

The COMPASSO mission and its iodine clock — •Frederik Kuschewski[1], Thilo Schuldt[1], Martin Gohlke[2], Markus Oswald[1], Jonas Bischof[1], Jan Wüst[1,3], Alex Boac[1], Andre Bussmeier[1], Klaus Abich[1], Tasmim Alam[1], Tim Blomberg[1], and Claus Braxmeier[1,3] — [1]DLR Institute of Quantum Technologies — [2]DLR Institute of Space Systems — [3]Ulm University

High-precision clock technologies have a variety of applications both in lab environments and in space, such as research of geodesy, test of relativity theory and also navigation with the GNSS (global navigation satellite system) network. However, the established clock technologies in space (rubidium standards and masers) lack in precision and long-term stability, limiting the accuracy of space research and navigation. Optical clocks have the potential to improve the performance by orders of magnitude, hence offering unprecedented accuracy in numerous fields of research and high-precision navigation [1]. The DLR COMPASSO mission will demonstrate the first optical clock technology in orbit and its payload will be installed on the Bartolomeo platform of the ISS with a scheduled launch in 2025. In this contribution, we will present the mission architecture and highlight the features of the ruggedized clock technology [2], which utilizes modulation transfer spectroscopy in molecular iodine yielding a long-term fractional stability of up to 10^{-15}. [1] Schuldt, T. et al. GPS Solut. **25**, 83 (2021). [2] Schuldt, T. et al. Appl. Opt. **56**, 4, (2017).

Q 47.5 Thu 12:15 E001

Vibration isolation and frequency feedforward techniques in ultra-stable laser systems. — •Sofia Herbers[1], Jialiang Yu[1], Jan Kawohl[1], Mattias Misera[1], Thomas Legero[1], Uwe Sterr[1], Anders Wallin[2], Kalle Hanhijärvi[2], Thomas Lindvall[2], and Thomas Fordell[2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Germany — [2]VTT Technical Research Center of Finland Ldt., Finland

To improve the performance of metrology and precision measurements with optical clocks, ultra-stable lasers with extremely low frequency instability are required. Amongst others, accelerations acting on the laser systems' ultra-stable resonators limit the frequency stability even though the resonators' acceleration sensitivity is reduced by novel mounting designs and the best commercially available vibration isolation systems are used to reduce vibrations.

To overcome this limitation, we investigate adding additional feedback corrections to a commercial vibration isolation platform as well as applying feedforward corrections to the laser frequency. Additional seismometers and a tiltmeter are placed on the vibration isolation platform to detect its movement. The sensor outputs are used to generate correction signals that are either sent back to the actuators of the vibration isolation platform or sent forward to the laser frequency.

We acknowledge support by the Project 20FUN08 NEXTLASERS, which has received funding from the EMPIR programme cofinanced by the Participating States and from the European Union*s Horizon 2020 Research and Innovation Programme.

Q 47.6 Thu 12:30 E001

E2-M1 polarisability of the strontium clock transition at the 813 nm lattice magic wavelength — •Joshua Klose, Sören Dörscher, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

To accurately determine the frequency shift of the clock transition caused by the optical lattice with fractional uncertainty of 10^{-17} or below, one must account for electric-quadrupole (E2) and magnetic-dipole (M1) interactions in a strontium lattice clock. However, the values of the E2-M1 polarisability difference of the clock states, $(5s^2)\,^1S_0$ and $(5s5p)\,^3P_0$, found in recent publications [1, 2] exhibit large discrepancies. We report on an independent experimental determination of the differential E2-M1 polarisability, $\Delta\alpha_{\mathrm{qm}}$, by measuring the differential light lattice shift between samples with different motional state distributions, leveraging the different dependence of the light shift terms on the atomic motional state. We find a value of $\Delta\alpha_{\mathrm{qm}} = -987^{+174}_{-223}\,\mu\mathrm{Hz}$, which is in agreement with the value reported in Ref. [1] as well as the result of another recent investigation [3].

This project has been supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2123 QuantumFrontiers – Project-ID 390837967, SFB 1464 TerraQ – Project-ID 434617780 – within project A04, and SFB 1227 DQ-*mat* – Project-ID 274200144 – within project B02.

[1] I. Ushijima *et al.*, Phys. Rev. Lett. **121**, 263202 (2018)
[2] S. G. Porsev *et al.*, Phys. Rev. Lett. **120**, 063204 (2018)
[3] K. Kim *et al.*, arXiv:2210.16374 (2022)

Q 47.7 Thu 12:45 E001

An indium ion clock with a systematic uncertainty on the 10^{-18}-level — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Nishant Bhatt[1], Moritz von Boehn[1], Ingrid Maria Dippel[1], Jonas Keller[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

Frequency is the most accurate physical property that can be measured by man-made machines. Nowadays, the best atomic clocks are based on optical transitions and reach systematic uncertainties around 1×10^{-18} surpassing the clocks that currently define the SI unit of time by a factor of 100 and more. Because of its intrinsically low sensitivities, $^{115}\mathrm{In}^+$ is a candidate for a clock with a systematic uncertainty on the 10^{-19}-level, not only for a single but also multiple indium ions. This so-called "multi-ion clock" allows for shorter averaging times to reach a given statistical uncertainty level [1,2].

In this talk, we will demonstrate clock operation with an $^{115}\mathrm{In}^+$ ion sympathetically cooled by three $^{172}\mathrm{Yb}^+$ ions in a segmented linear Paul trap. The systematic uncertainty is evaluated on the 10^{-18}-level. The setup is optimized for clock operation with multiple $^{115}\mathrm{In}^+$ ions allowing for a similar systematic uncertainty as a single-ion clock [1]. First clock operation with multiple indium ions featuring individual state readout on an EMCCD camera is shown and discussed.

[1] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012)
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019)

Q 48: Optomechanics II

Time: Thursday 11:00–13:00 Location: E214

Invited Talk Q 48.1 Thu 11:00 E214

Using optomechanical systems to test gravitational theory – possibilities and limitations — •Dennis Rätzel — ZARM, University of Bremen, 28359 Bremen, Germany — Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany

More than 100 years after the first development of a relativistic theory of gravity, there is an ever-increasing amount of predicted, yet untested, phenomena and unsolved scientific puzzles revolving around gravity. There are many proposals to apply quantum sensors to test for such phenomena or experimentally resolve some of the puzzles. In this talk, I will present my perspective on three proposals based on optomechanical systems: measurement of the gravitational field of light and relativistic particle beams, obtaining bounds on Chameleon-field dark energy models, and testing for quantum properties of the gravitational field. I will give a short introduction to the models involved and discuss fundamental constraints.

Q 48.2 Thu 11:30 E214

Force-Gradient Sensing and Entanglement via Feedback Cooling of Interacting Nanoparticles — •Henning Rudolph[1], Uros Delic[2], Markus Aspelmeyer[2,3], Klaus Hornberger[1], and Benjamin Stickler[1] — [1]University of Duisburg-Essen, Duisburg, Germany — [2]University of Vienna, Vienna, Austria — [3]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Vienna, Austria

The motion of levitated nanoparticles has recently been cooled into the quantum groundstate by electric feedback [1,2]. In this talk, we show theoretically that feedback-cooling of two levitated, interacting nanoparticles enables differential sensing of forces and the observation of stationary entanglement [3]. The feedback drives the particles into a stationary, non-thermal state which is susceptible to inhomogeneous force fields. We predict that force-gradient sensing at the zepto-Newton per micron range is feasible and that entanglement due to the interaction between charged particles is possible if the detection efficiency of the feedback loop exceeds the ratio of the mechanical normal mode frequencies.

[1] Magrini et al. "Real-time optimal quantum control of mechanical motion at room temperature." Nature (2021)
[2] Tebbenjohanns et al. "Quantum control of a nanoparticle optically levitated in cryogenic free space." Nature (2021)
[3] Rudolph et al. "Force-Gradient Sensing and Entanglement via Feedback Cooling of Interacting Nanoparticles." Physical Review Letters (2022)

Q 48.3 Thu 11:45 E214

A hybrid optomechanical system of an optically levitated nanoparticle and an optical microcavity in a resolved sideband regime — •Zijie Sheng[1,2], Seyed Khalil Alavi[1,2], Harald Giessen[3], Haneul Lee[4], Hansuek Lee[4], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universität Stuttgart, 70569 Stuttgart, DE — [2]Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, DE — [3]4th Physics Institute, Universität Stuttgart, 70569 Stuttgart, DE — [4]Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon, 34141, Korea

An optically levitated dielectric nanoparticle coupled to an optical cavity has recently emerged as an optomechanical system with unique features that allow for quantum experiments at room temperature. The field has shown rapid progress in the past few years, including cooling of the particle's motion down to the ground state, achieved with a conventional Fabry-Pérot optical cavity in a resolved sideband regime. We present a new type of optomechanical system comprising a nanoparticle in an optical tweezer and a monolithic optical microcavity in a resolved sideband regime. We use a silica microtoroid as an optical cavity with a Q factor of up to 10^8. The optomechanical coupling is realized through the evanescent field when the particle is near the microtoroid. At a few hundred nanometers from the surface, the coupling of up to tens of kHz can be achieved, five orders of magnitude larger than the previous work with a bulk optical cavity. We discuss our progress toward attaining strong quantum cooperativity.

Q 48.4 Thu 12:00 E214

Phase locking of two levitated nanoparticles via non-reciprocal dipole-dipole coupling — •Manuel Reisenbauer[1], Livia Egyed[1], Murad Abuzarli[1], Anton Zasedatelev[1,2], Henning Rudolph[3], Klaus Hornberger[3], Aspelmeyer Markus[1,2], Benjamin A. Stickler[3], and Uros Delic[1,2] — [1]University of Vienna, A-1090 Vienna, Austria — [2]Austrian Academy of Sciences, A-1090 Vienna — [3]University of Duisburg-Essen, 47048 Duisburg, Germany

Arrays of optically levitated dielectric particles are a novel platform for exploring collective optomechanical dynamics. Recently, strong tunable dipole-dipole and electrostatic interaction have been demonstrated between several levitated particles.

We built an experiment based on an optical trap array of silica nanoparticles. Our platform enables independent control of particle dynamics and non-reciprocal dipole-dipole interactions together with a readout for individual particle motions. We employ a fully non-reciprocal coupling to drive the particles motion into self-sustained oscillations. We observe a phase transition into a collectively synchronized state of motion which we characterize via phase locking.

Our work has possible applications for sensing and metrology employing the reduction of phase noise below the thermomechanical limit of each individual oscillator. Finally, we will discuss the scalability of our system to large arrays of trapped particles.

Q 48.5 Thu 12:15 E214

Superconducting Quantum Magnetomechanics — •Christian M.F. Schneider[1,2,6,7], David Zöpfl[1,2], Mathieu L. Juan[3], Nicolas Diaz-Naufal[4], Lukas F. Deeg[1,2], Aleksei Sharafiev[1,2], Anja Metelmann[4,5], and Gerhard Kirchmair[1,2] — [1]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, 6020 Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, 6020 Innsbruck, Austria — [3]Institut Quantique and Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, J1K 2R1, Canada — [4]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [5]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [6]Technical University of Munich, Physics Department, 85747 Garching, Germany — [7]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

Quantum control of massive mechanical resonators has come within reach in recent years. In this talk, I describe an experimental setup in which we couple magnetic cantilevers to a superconducting microwave resonator or a transmon. When cooled down to mK temperatures, we achieve high and tunable coupling strengths, and could demonstrate control over the mechanical system in form of feedback cooling to around 10 phonons. The intrinsic nonlinearity of the microwave circuit gives rise to a more power efficient cooling performance. For the ultimate goal of quantum control, we couple a transmon directly to the cantilever and show some first characterization measurements.

Q 48.6 Thu 12:30 E214

Nonclassical photon statistics in two-tone continuously driven optomechanics — •Kjetil Borkje[1], Francesco Massel[1], and Jack Harris[2,3] — [1]Department of Science and Industry Systems, University of South-Eastern Norway, PO Box 235, NO-3603 Kongsberg, Norway — [2]Department of Physics, Yale University, 217 Prospect Street, New Haven, Connecticut 06520, USA — [3]Department of Applied Physics, Yale University, 15 Prospect Street, New Haven, Connecticut 06520, USA

We present a study of a standard optomechanical system where the cavity mode is continuously driven at two different frequencies, and where sideband photons are detected by single photon detectors after frequency filtering the output from the cavity mode around its resonance frequency. We first derive the normalized second order coherence associated with the detected photons, and show that it contains signatures of the quantum nature of the mechanical mode which would be absent with only single-tone driving. To identify model-independent nonclassical features, we derive two inequalities for the sideband photon statistics that should be valid in any classical model of the system. We show that these inequalities are violated in the proposed setup. This is provided that the average phonon occupation number of the mechanical mode is sufficiently small, which in principle can be achieved through sideband cooling intrinsic to the setup. The proposed setup thus employs a mechanical oscillator in order to generate a steady-state source of nonclassical radiation.

[1] Børkje et al., Physical Review A, 104, 063507 (2021)

Q 48.7 Thu 12:45 E214

Dissipative cavity optomechanics with a suspended frequency-dependent mirror — Sushanth Kini Manjeshwar[1], Anastasiia Ciers[1], •Juliette Monsel[1], Cindy Peralle[2], Shu Min Wang[1], Philippe Tassin[2], and Witlef Wieczorek[1] — [1]Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-412 96 Göteborg, Sweden — [2]Department of Physics, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

Cavity optomechanics with a strongly frequency-dependent mirror, such as a photonic crystal mirror, offers novel capabilities in manipulating mechanical motion, such as the implementation of efficient cooling. Here, we build an input-output-based description of such an optomechanical system, generalizing Ref. [1] by including in our model a dissipative optomechanical coupling arising from the change in the loss rate of the cavity due to the mechanical motion. We then analyze the optomechanical properties of the system, in particular the mechanical frequency shift and optomechanical cooling. Finally, we show how our model matches our experimental measurements of a chip-based microcavity. Our setup consists of a suspended photonic crystal mirror [2] and a distributed Bragg reflector mirror, forming a free-space, Fabry-Pérot-type optomechanical microcavity with a length less than the optical wavelength and approaching the ultra-strong coupling regime.

[1] O. Černotík, A. Dantan, C. Genes, Phys. Rev. Lett. 122, 243601 (2019)
[2] S. Kini Manjeshwar, et al., Appl. Phys. Lett. 116, 264001 (2020)

Q 49: Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)

Time: Thursday 11:00–13:00 Location: F303

Invited Talk Q 49.1 Thu 11:00 F303

Trapping Ions and Ion Coulomb Crystals in a 1D Optical Lattice — •Daniel Hoenig[1], Fabian Thielemann[1], Joachim Welz[1], Wei Wu[1], Thomas Walker[1], Leon Karpa[2], Amir Mohammadi[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs Universität, Freiburg, Germany — [2]Leibniz Universität, Hannover, Germany

The long-range Coulomb interaction between ions and the dependence of the trapping potential on the internal electronic state of the ions make optically trapped ion Coulomb crystals an interesting platform for quantum simulations. Optical lattices further extend this platform by providing arrays of individual microtraps for the ions.

In the past, we reported the successful trapping of a single ion in a one-dimensional optical lattice as well as of ion Coulomb crystals in a single-beam optical dipole trap. In this talk, we present recent advancements in trapping 138Ba+ ions in a one-dimensional optical lattice at a wavelength of 532nm and the first successful trapping of linear ion Coulomb crystals ($N \leq 3$) in such a trap array. The observed eigenfrequencies of the ions in the lattice and the increased robustness against axial electric fields provide evidence for the single-site confinement of the ions at individual lattice sites.

As optical lattices are extendable in size and dimension, they might allow for the realization of ion-microtrap structures in 2D and 3D. Additionally, the absence of micromotion in optical traps could give them an edge over rf-traps in applications, where heating and decoherence induced by micromotion become limiting factors, as for example, the study of atom-ion interactions at ultracold temperatures.

Q 49.2 Thu 11:30 F303

Catalyzation of supersolidity in binary dipolar condensates — •Daniel Scheiermann[1], Luis Ardila[2], and Luis Santos[3] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

reakthrough experiments have newly explored the fascinating physics of dipolar quantum droplets and supersolids. The recent realization of dipolar mixtures opens further intriguing possibilities. We show that under rather general conditions, the presence of a second component catalyzes droplet nucleation and supersolidity in an otherwise unmodulated condensate. For miscible mixtures, droplet catalyzation results from the effective modification of the relative dipolar strength, and may occur even for a surprisingly small impurity doping. We show that different ground-states may occur, including the possibility of two coexisting interacting supersolids. The immiscible regime provides a second scenario for double supersolidity in an array of immiscible droplets. In addition, we will discuss how the superfluidity of this mixture can be tested.

Q 49.3 Thu 11:45 F303

Controlling superfluid flows using dissipative impurities — •Martin Will[1], Jamir Marino[2], Herwig Ott[1], and Michael Fleischhauer[1] — [1]University of Kaiserslautern-Landau, Germany — [2]Johannes Gutenberg University Mainz, Germany

We propose and analyze a protocol to create and control the superfluid flow in a one dimensional, weakly interacting Bose gas by noisy point contacts. Considering first a single contact in a static or moving condensate, we identify three different dynamical regimes: I. a linear response regime, where the noise induces a coherent flow in proportion to the strength of the noise, II. a Zeno regime with suppressed currents, and III. a regime of continuous soliton emission. Generalizing to two point contacts in a condensate at rest we show that noise tuning can be employed to control or stabilize the superfluid transport of particles along the segment which connects them.

Q 49.4 Thu 12:00 F303

Atom-number enhancement by shielding atoms from losses in strontium magneto-optical traps — •Vasiliy Makhalov[1], Jonatan Höschele[1], Sandra Buob[1], Antonio Rubio[1], and Leticia Tarruell[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]Pg. Lluís Companys 23, 08010 Barcelona, Spain

Strontium offers many exciting opportunities for ultracold-atom experiments. For example, the most precise atomic clocks to date utilize the ultra-narrow clock transition of ^{87}Sr. Strontium also finds applications in atom quantum computing, interferometers, superradiant lasers, the generation of continuous-wave BEC, and quantum simulations. Most of these applications can benefit from a higher number of atoms.

In my talk, I will present a method to enhance the atom number in a 461-nm MOT of strontium without increasing the experimental complexity. This is achieved via saturation of the $^1S_0 \rightarrow {}^3P_1$ intercombination-line transition with intense resonant light. This continuously populates a short-living reservoir in the $^3P_1$ state and shields part of the atoms from the intrinsic losses of the 461-nm MOT cooling cycle. Such enhancement approximately doubles the atom number of the MOT of bosonic (^{88}Sr and ^{84}Sr) or fermionic (^{87}Sr) isotopes. Most of the strontium experiments can readily apply this technique without changes in the apparatus. I will also discuss the application of the shielding mechanism to other atomic species.

Q 49.5 Thu 12:15 F303

From single to binary dipolar supersolids: a platform offering possibilities beyond imagination — •Albert Gallemi — Institut für Theoretische Physik, Leibniz Universität Hannover

Recent breakthrough experiments on dipolar condensates have reported the creation of supersolids. Supersolids have been observed both in elongated and oblate geometries, where they display themselves as 1D and 2D array of quantum droplets. In a single-component dipolar system, two main parameters (the ratio between dipolar and contact interactions and the density) can trigger different ground state configurations, in terms of different density patterns. As a result, apart from droplet arrays, one can observe the formation of honeycomb patterns and other kind of structure subject to randomness under the presence of an external confinement providing finite-size effects.

When two dipolar components coexist, the miscible-immiscible transition (which now depends on the dipole-dipole interaction) and the quantum number m_F corresponding to the condensed components (both in modulus and sign) play a role. We will analyse the different paths that open thanks to these extra degrees of freedom. We will also comment about the particular case of coherently Rabi-coupled dipolar mixtures, where polarization becomes a key observable. Rabi coupling also provides an intriguing power to the beyond-mean-field Lee-Huang-Yang correction, which can make the physics of droplets and supersolids to behave in a dramatically different way.

Q 49.6 Thu 12:30 F303

Quantum fluctuations in one-dimensional supersolids — •Chris Bühler, Tobias Ilg, and Hans Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Scienceand Technology, University of Stuttgart, DE-70550 Stuttgart, Germany

In one-dimension, quantum fluctuations prevent the appearance of long-range order in a supersolid, and only quasi long-range order can survive. We derive this quantum critical behavior and study its influence on the superfluid response and properties of the solid. The analysis is based on an effective low-energy description accounting for the two coupled Goldstone modes. We find that the quantum phase transition from the superfluid to the supersolid is shifted by quantum fluctuations from its mean-field prediction. However, for current experimental parameters with dipolar atomic gases, this shift is not observable and the transition appears to be mean-field like.

Q 49.7 Thu 12:45 F303

Supersolidity and Bloch oscillations in dipolar quantum gases — •Manfred Mark — Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria

Since strongly dipolar quantum gases made from lanthanide atoms were successfully brought to degeneracy 10 years ago, they have proven to be a rich source of new and fascinating phenomena arising from the long-range and anisotropic dipole-dipole interactions. Here, we will present the latest results from our erbium and dysprosium quantum gas experiments in Innsbruck. Following the recent discovery of supersolid states, we have studied its lifecycle from the formation to its death [1]. We also discuss our latest observation of supersolidity in two dimensions [2]. Finally, we investigated the properties of strongly dipolar gases within an array of two-dimensional traps [3] using Bloch oscillations and detected a transition to a stable self-focusing state which occupies only a single lattice plane, and predict the possibility of preparing dipolar solitons.

[1] M. Sohmen et al., Phys. Rev. Lett. 126, 233401 (2021) [2] M. A. Norcia et al., Nature 596, 357-361 (2021) [3] G. Natale et al., Commun. Phys., 5, 227 (2022)

Q 50: Quantum Gases: Fermions I

Time: Thursday 11:00–13:00 Location: F342

Q 50.1 Thu 11:00 F342

Collective excitations in mesoscopic Fermi gases — •Philipp Lunt, Paul Hill, Johannes Reiter, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg

Understanding the elementary excitations of strongly interacting many-body systems in terms of the independent motion of individual particles and their collective behaviour has been a central theme in many fields ranging from nuclear physics to cold atoms [1,2].

Here, we present a study of elementary excitations of a mesoscopic Fermi system across the BEC-BCS crossover by means of spectroscopic probes. Therefore, we use an established spilling technique [3] to prepare a balanced system of few fermionic atoms in a tightly confined tweezer. We excite the quadrupole mode by interference with a Laguerre-Gaussian mode. Tuning of the interparticle interactions via a broad Feshbach resonance allows us to observe the transition from single-particle to collective excitations. Furthermore, we investigate the breakdown of collectivity by reducing the atom number gradually.

[1] B. Mottelson Science 193 (4250), 287-294 (1976) [2] S. Giorgini et al. Rev.Mod.Phys. 80, 125 (2008) [3] F. Serwane et al. Science 332 (6027), 336-338 (2011)

Q 50.2 Thu 11:15 F342

Anomalous thermoelectric transport between fermionic superfluids — Philipp Fabritius, Jeffrey Mohan, Mohsen Talebi, Simon Wili, •Meng-Zi Huang, and Tilman Esslinger — Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

Thermoelectric effects in superfluid systems have been far less explored than other superfluid transport both theoretically and experimentally. Landau's two-fluid model works well in conventional superconductors, yet studies beyond the two-fluid model are scarce. Here we study the Peltier and Seebeck effects together in a superfluid system, namely transport induced by a chemical potential bias and by a temperature bias, respectively. Our system is a mesoscopic channel connecting two superfluids of ultracold fermionic atoms, where the particle current in both the Peltier and the Seebeck configurations exhibits a strong non-Ohmic character. While non-Ohmic transport is associated with superfluid features, we observe a large entropy current concomitant with the particle current, incompatible with a simple two-fluid model. On the other hand, we engineer a controlled particle loss inside the mesoscopic channel to study its influence on thermoelectric response. Surprisingly, local dissipation can enhance the particle current in a Seebeck configuration (analogous to the fountain effect). This would imply a change in the reservoir response despite the dissipation being in the channel. We present possible explanations to the observations, including non-hydrodynamic transport.

Q 50.3 Thu 11:30 F342

Observation of Cooper pairs in a mesoscopic 2D Fermi gas — •Marvin Holten[1,2], Luca Bayha[1], Keerthan Subramanian[1], Sandra Brandstetter[1], Carl Heintze[1], Philipp Lunt[1], Philipp Preiss[1,3], and Selim Jochim[1] — [1]Physikalisches Institut, Heidelberg University, Germany — [2]Atominstiut, TU Wien, Austria — [3]Max Planck Institute of Quantum Optics, Garching, Germany

The formation of strongly correlated pairs is fundamental for the emergence of fermionic superfluidity and superconductivity. To understand the pairing mechanism is an ongoing challenge in the study of many strongly correlated fermionic systems. In this talk, I present the direct observation of Cooper pairs in our experiment. We have implemented a fluorescence imaging technique that allows us to extract the full insitu momentum distribution with single particle and spin resolution. We apply it to a mesoscopic Fermi gas, prepared deterministically in the ground state of a two-dimensional harmonic oscillator. Our ultracold gas allows us to tune freely between a completely non-interacting unpaired system and weak attractions where we find Cooper pair correlations at the Fermi surface. When increasing the interactions even further, the pair character is modified and the pairs gradually turn into tightly bound dimers. The collective behaviour that we discover in our mesoscopic system is closely related to observations in nuclear physics or metallic grains. Our method provides a new pathway to study many of the outstanding questions concerning fermionic pairing, for example in imbalanced systems or the normal phase.

Q 50.4 Thu 11:45 F342

Tunable diffusion properties of spin-polarized Fermi gases in time-dependent disorder — •Sian Barbosa, Max Kiefer-Emmanouilidis, Felix Lang, Michael Fleischhauer, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

The transport of particles through disordered potential landscapes has been actively studied for the last decades. The vast majority of these studies, e.g. of Anderson localization, addressed the regime in which the disordered potential is static. However, it seems natural to investigate the influence of time-dependent disorder on transport properties. More specifically, a crossover from localization to diffusive, even hyperballistic, transport is expected to occur when the disorder varies in time. I will present the results of our experimental investigation of the dynamics of ultracold, spin-polarized fermionic lithium atoms when exposed to an optical speckle potential that can be frozen or continuously varying its random pattern in both space and time. We observe a strong dependence of the system's diffusion exponent on the so-called correlation time, a measure for the disorder's rate of change. We furthermore investigate new measures based on analysis of entropies to quantify the state of the system independent of specific models.

Q 50.5 Thu 12:00 F342

Competing antiferromagnetic and superfluid phases in the Feshbach-Hubbard model — •Victor Bezerra[1] and Axel Pelster[2] — [1]Friedrich-Engels-Gymnasium, Emmentalerstraße 67, 13407 Berlin, Germany — [2]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

Competing phases play an important role in strongly interacting systems, as for example in the case of superconductivity and antiferromagnetism. Alongside condensed matter-systems ultracold atoms loaded in optical lattices have shown to be quite promising to simulate and to understand the behavior of strongly correlated systems. In this work we study a two-dimensional model that contains both the usual repulsive Fermi-Hubbard Hamiltonian and a pairing term due Feshbach bosons, and study there the competition of antiferromagnetic order and conventional pairing order within a zero-temperature mean-field theory. With this we investigate, at first, the properties of the crossover from a Bose-Einstein condensate (BEC) phase to the Bardeen-Cooper-Schrieffer (BCS)-like phase, where a reentrant behavior occurs and band-insulator lobes are obtained analytically. Secondly, concerning the antiferromagnetic (AF) order, the well-known mean-field results are reproduced. And, finally, we obtain a quantum phase diagram, which reveals an intriguing interplay from a BEC-BCS crossover to an insulating AF order.

Q 50.6 Thu 12:15 F342

Report on an Erbium-Lithium machine — •Florian Kiesel and Alexandre De Martino — Eberhard Karls Universität Tübingen, Physikalisches Institut AG Groß, Auf der Morgenstelle 14, 72076 Tübingen

Ultracold Fermions cannot be cooled below about 10% of the Fermi temperature with conventional methods. Sympathetic cooling with a classical gas as an entropy reservoir may provide a new direction to overcome the current limit. Here we report on the construction and implementation of first cooling stages of a two species apparatus for the optimized symp. cooling of fermionic Li with bosonic Er. This mixture has several promising features, that have not yet been utilized for symp. cooling in any other mixture. Pushing the temperature limit is essential for the quantum simulation of strongly correlated phenomena, in particular in optical lattice.

Q 50.7 Thu 12:30 F342

Excitation Spectrum and Superfluid Gap of an Ultracold Fermi gas — •Hauke Biss[1,2], Lennart Sobirey[1], René Henke[1], Cesar Cabrera[1,2], and Henning Moritz[1,2] — [1]Institute of Laser Physics, University of Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Hamburg, Germany

Ultracold Fermi gases with tunable interactions have allowed realizing the famous BEC-BCS crossover from a Bose-Einstein condensate (BEC) of molecules to a Bardeen-Cooper-Schrieffer (BCS) superfluid of weakly bound Cooper pairs. In this contribution, I will present how we use Bragg spectroscopy to measure the full momentum-resolved low-energy excitation spectrum of spin-balanced strongly interacting ultracold Fermi gases. This enables us to observe the smooth transformation from a bosonic to a fermionic superfluid in the BEC-BCS crossover. We use our spectra to determine the evolution of the superfluid gap and find excellent agreement with previous experiments and theory. As a next step, we reduce the dimensionality of the gas to probe the excitation spectrum of two-dimensional (2D) Fermi gases. This allows us to demonstrate superfluidity of 2D Fermi gases and to observe the influence of the reduced dimensionality on the stability of the superfluid phase. Finally, I will present our progress towards creating and probing spin-imbalanced mixtures in 2D.

Q 50.8 Thu 12:45 F342

Towards fast, deterministic preparation of few-fermion states — •Maximilian Kaiser[1], Tobias Hammel[1], Vivienne Leidel[1], Micha Bunjes[1], Philipp Preiss[2], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut - University of Heidelberg, Heidelberg, Germany — [2]Max Planck Institute of Quantum Optics, Garching, Germany

Measurements of higher-order correlations in quantum systems, e.g. for the tomography of complex quantum states, require large data sets. This demand stands in contrast to typical cycle times of 10 seconds or more in traditional experiments with ultracold quantum gases.

We report on the ongoing development of a highly modular apparatus for fast, experimental quantum simulations using ultracold Lithium-6 with envisioned cycle times of well below 1 second. Within each run, few-fermion states are prepared in a sequence based upon [1].

The resulting high data output will especially be key for iteration-intensive research in the future, while the highly modular experimental interface allows a broad envelope of quantum systems to be realized and simulated.

[1] F.Serwane et Al., Science Vol. 332, p.336-338 (2011)

Q 51: Precision Measurements

Time: Thursday 14:30–16:30 Location: A320

Q 51.1 Thu 14:30 A320

Search of dark matter boson via isotope shift measurements in ytterbium ions — •Chih-Han Yeh[1], Laura S. Dreissen[1], Melina Filzinger[1], Nils Huntemann[1], Henning A. Fürst[1,2], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Astronomical observations support the existence of dark matter, but its origin and composition are unknown. A dark matter boson coupling neutrons and electrons in an atom could be observed with isotope shift measurements and a so-called King-plot analysis [1-3]. Here, known atomic and nuclear effects that dominate the isotope shift follow a linear scaling. We performed accurate isotope shift measurements in trapped ytterbium ions to search for these interactions via non-linearities in the King-plot. We determined the absolute frequencies of the $^2S_{1/2} \rightarrow {}^2D_{5/2}$ and $^2S_{1/2} \rightarrow {}^2F_{7/2}$ transitions in all 5 stable even isotopes of Yb^+ to the $\sim$10 Hz level. We reproduce the non-linearities observed in Ref. [4], but reach a 10 to 100 fold higher accuracy. With these results we hope to shed light onto the source of the observed non-linearity and investigate a possible coupling from a new boson beyond the previously explored parameter range.

[1] C. Delaunay, et al., *Phys. Rev. D* **96**, 093001 (2017). [2] J. C. Berengut, et al., *Phys. Rev. Lett.* **120**, 091801 (2018). [3] W. H. King, *Isotope Shifts in Atomic Spectra* (Plenum Press, New York, 1984). [4] J. Hur, et al., *Phys. Rev. Lett.* **128**, 163201 (2022.)

Q 51.2 Thu 14:45 A320

Measuring Beam Deflections via Weak Value Amplification — •Elina Köster[1,2], Carlotta Versmold[1,2], Jan Dziewior[1,2], Florian Huber[1,2], Jasmin DA Meinecke[1,2], Lev Vaidman[1,2,3], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel

The technique of weak value amplification was already used to precisely measure small deflections of light. Yet, so far the interaction region was included in the measurement device, when e.g. measuring a tiny deflection of a light beam [1]. Here we introduce an interferometric weak measurement setup able to measure displacements and deflections of a light beam that occur outside of the measuring device. This is achieved by spatially separating the arms of a Sagnac interferometer and inserting a Dove prism in one of them.

Due to the mirroring of one of the arms the center of mass of the resulting interference pattern depends on the initial deflection of the beam. Amplified by the weak value of the system this allows a highly sensitive determination of the deflection or displacement.

[1] Dixon et al, "Ultrasensitive beam deflection measurement via interferometric weak value amplification.", Physical review letters, 102.17 (2009): 173601

Q 51.3 Thu 15:00 A320

The Photon-Per-Day Detection System of the ALPS II Ex-

periment — •Daniel Brotherton for the ALPS II-Collaboration — University of Florida, Gainesville FL, U.S.

Axions and axion-like particles are a class of particles extending the Standard Model. The Any Light Particle Search II (ALPS II) will soon begin its first science run to probe their miniscule interaction with light. ALPS II follows the "light shining through a wall" approach. Laser light directed through a magnetic field towards a wall may convert into axions and cross unimpeded. On the opposite side, the axions may reconvert to light amidst another magnetic field and be detected. With respect to ALPS II's design parameters and target sensitivity, a detector is required capable of resolving on the order of a photon per day over a 20-day measurement run. In this talk, I will introduce ALPS II's heterodyne interferometric detection scheme. I will discuss the characterization of the detector scheme's noise background and the amount of stray light leaked into the reconversion region.

This work is supported by NSF grant PHY-2110705 and Heising Simons foundation grant 2020-1841.

Q 51.4 Thu 15:15 A320

Characterization of the Optical Systems in the ALPS II Experiment — •Todd Kozlowski for the ALPS II-Collaboration — DESY, Hamburg, Germany

The Any Light Particle Search II (ALPS II) is a "light-shining-through-the-wall" particle search experiment at DESY, currently in its final preparations for a science run. ALPS II will probe for axions and axion-like particles, a family of hypothetical particles outside of the Standard Model, to a sensitivity unparalleled by other model-independent, laboratory-based experiments and most other broadband experiments. ALPS II aims to detect light which has undergone photon-axion and subsequent axion-photon conversion in the presence of a magnetic field. In the initial design, a 60 W laser provides a constant flux of photons for conversion. Opposite a light-blocking shutter, a 122 meter long, high finesse 'regeneration cavity' increases the reconverted signal rate. The resulting ultra-weak signal field can then be detected using optical heterodyne interferometry. In this presentation, I will characterize our optical and control systems in the context of the requirements for the first science measurement. These results will include the performance of the very long storage-time regeneration cavity and the position and phase stability of the fields on the experiment's central optical breadboard.

This work is supported by NSF grant PHY-2110705 and Heising Simons foundation grant 2020-1841.

Q 51.5 Thu 15:30 A320

Indirect excitation mechanisms for the ^{229}Th isomer — •Tobias Kirschbaum[1], Nikolay Minkov[2], and Adriana Pálffy[1] — [1]Julius-Maximilians-Universität Würzburg, Germany — [2]Institute for Nuclear Research and Nuclear Engineering, Sofia, Bulgaria

Amongst all nuclei, the ^{229}Th nucleus presents the lowest first excited state at around 8 eV with an expected radiative lifetime of a few hours. Hence, this transition should be accessible with VUV light. In combination with its narrow linewidth, this renders ^{229}Th an ideal candidate for a nuclear clock with excellent accuracy and stability [1]. However, a hindrance towards its experimental realization is the relatively large uncertainty on the transition energy which makes direct laser excitation cumbersome.

Here, we investigate theoretically two different approaches to indirectly populate ^{229}Th's isomeric state. The first approach deals with quantum optical transfer schemes involving STIRAP and π-pulses via the second excited state at 29.19 keV at the Gamma Factory [2]. The second approach considers Electronic Bridge (EB) schemes in a VUV-transparent crystal environment doped with ^{229}Th [3]. Here, EB involves electronic defect states which appear in the band gap due to ^{229}Th doping. We present different EB schemes and the corresponding excitation rates for ^{229}Th:LiCAF.

[1] E. Peik *et al.*, Quantum Sci. Technol. **6**, 034002 (2021).
[2] T. Kirschbaum, N. Minkov and A. Pálffy, Phys. Rev. C **105**, 064313 (2022).
[3] B. S. Nickerson *et al.*, Phys. Rev. A **103**, 053120 (2021).

Q 51.6 Thu 15:45 A320

Recent Developments towards the Lifetime Measurement of the ^{229m}Th Nuclear Clock Isomer — •Kevin Scharl[1], Daniel Moritz[1], Mahmood Hussain[1], Sandro Kraemer[1,2], Lilli Löbell[1], Florian Zacherl[1], Shiqian Ding[3], Benedict Seiferle[1], and Peter G. Thirolf[1] — [1]LMU Munich — [2]KU Leuven, Belgium — [3]Tsinghua University, Beijing, China

The elusive thorium-229 isomer (^{229m}Th) with its unusually low-lying first excited state (8.338±0.024 eV) represents the so far only candidate for the realization of an optical nuclear clock. Possible applications of a nuclear clock are not limited to highly precise time keeping, but reach into many other fields from geodesy to fundamental physics studies as dark matter research. Considerable progress was achieved in the past few years to characterize ^{229m}Th, from its first identification to recent observations of the long-searched radiative decay channel. While the determination of the nuclear resonance with laser-spectroscopic precision is still awaited, a measurement of the ionic lifetime of the isomer is being prepared by our group. There is experimental proof for the lifetime to last 10^3-10^4 s. To precisely target the quantity by hyperfine structure spectroscopy our experimental setup is based on a cryogenic Paul trap providing long enough storage of cooled ^{229m}Th. The talk will present the status of the experimental setup and first tests to characterize the cryogenic confinement of ^{229m}Th ions together with laser ablated $^{88}Sr^+$ ions, their sympathetic Doppler cooling and the spectroscopic readout of the trapped ion states. This work was supported by the European Research Council (ERC): Grant agreement No. 856415.

Q 51.7 Thu 16:00 A320

Towards VUV laser spectroscopy of the nuclear clock isomer 229mTh — •Mahmood Hussain[1], Johannes Weitenberg[2,3], Stephan H. Wissenberg[2], Tamila Rozibakieva[1], Hans-Dieter Hoffmann[2], Constantin L. Häfner[2,4], and Peter G. Thirolf[1] — [1]LMU Munich — [2]Fraunhofer ILT Aachen — [3]Max-Planck Institute of Quantum Optics, Garching — [4]RWTH Aachen University

The isotope 229-Thorium features a low-energy (approx. 8.3 eV) isomeric first nuclear excited state, the so-called thorium isomer. Its long coherence time and vacuum ultraviolet (VUV) transition energy make it the only nuclear transition that is accessible with current laser technology and therefore highly desirable for a clock operation. The small nuclear moments make the nuclear clock a unique quantum sensor to probe, e.g., dark matter or spatio-temporal fluctuations of fundamental constants. To drive the nuclear transition, we are developing a tabletop approx. 150 nm frequency comb that combines a high-power ultrastable frequency comb at 1050 nm, nonlinear pulse compression, and an enhancement resonator to produce VUV high power per comb mode (1 nW/mode) and a narrow comb linewidth (approx. 1 kHz) via high harmonic generation in Xe gas jet. Besides the VUV comb development, other challenges include, (i) coupling VUV pulses with trapped thorium ion(s) for coherent nuclear excitation and, (ii) orders of magnitude reduction in uncertainty of the transition frequency. The VUV comb's concept, the aforementioned challenges, and their prospective solutions will be discussed. Funding: European Research Council (ERC Synergy Grant, Agreement No. 856415).

Q 51.8 Thu 16:15 A320

Towards a Spaceborne Two-Photon Rubidium Frequency Reference — •Julien Kluge[1,2], Klaus Döringshoff[1,2], Daniel Emanuel Kohl[1,2], Moritz Eisebitt[2,3], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik, Humboldt-Universität zu Berlin — [3]II. Physikalisches Institut, RWTH Aachen University

Optical frequency standards based on two-photon spectroscopy using hot rubidium vapor are a promising candidate for realization of simple and compact optical clocks for application in next generation global navigation satellite systems.

In this presentation, we show the development of a two-photon frequency reference using FM spectroscopy at 778 nm for application in the CRONOS satellite mission. Recent results of our lab-based setups show a fractional instability below 3×10^{-13} per $\tau^{-1/2}$ for up to 1000 s. We present our design and first prototype of a spectroscopy module with a volume below 1/2 l, weight below one kilogramm and planned power budget of under 10 W for accommodation on a micro satellite. Additionally, reports on its performance and qualification for an in orbit verification mission are given. We further provide details on the architecture of the payload, the laser system for two-photon spectroscopy and the anticipated operation as part of an optical clock.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971, 50WM2164.

Q 52: Floquet Engineering and Topology

Time: Thursday 14:30–16:30 Location: E001

Invited Talk Q 52.1 Thu 14:30 E001

Nonperturbative Floquet engineering and Floquet-dissipative state preparation — •Francesco Petiziol — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstraße 36, 10623 Berlin, Germany

Time-periodic driving of quantum systems is a powerful tool for realizing effective Hamiltonians with desired properties (so-called "Floquet engineering") and, thus, for quantum simulation. Typical Floquet engineering techniques rely on perturbative approximations and can be categorized into "continuous" or "digital", depending whether they employ continuous time-dependent modulations, or stepwise evolutions with time-independent Hamiltonians. I will present a hybrid continuous-digital approach that allows one to engineer local coupling terms (such as three- and four-body couplings) in a nonperturbative and scalable fashion. This approach allows for the robust engineering of Kitaev's toric-code Hamiltonian, the paradigmatic model of a topological spin liquid, which involves purely four-spin interactions. I will, moreover, discuss how eigenstates of an effective Floquet-engineered Hamiltonian can be prepared and stabilized by coupling the system to artificial baths in superconducting circuits, by generalizing approaches of reservoir engineering. In particular, I will discuss the preparation of ground states of bosonic ladders with artificial magnetic flux.

Q 52.2 Thu 15:00 E001

Preparing and probing bosonic Chern-insulator analogs using Mott states or disorder — •Isaac Tesfaye[1], Botao Wang[2], and André Eckardt[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Université Libre de Bruxelles

Mimicking fermionic Chern insulators with bosons has drawn a lot of interest in experiments by using, for example, cold atoms [1,2] or photons [3]. Here we present a scheme to prepare and probe a bosonic Chern insulator analog by using (a) an ensemble of randomized bosonic states and (b) an initial Mott state configuration. By applying a staggered superlattice, we can identify the lowest band with individual lattice sites. The delocalization over this band in quasimomentum space is then achieved by introducing on-site disorder or local random phases (a). Switching off the interactions and adiabatically decreasing the superlattice then gives rise to a bosonic Chern insulator, whose topologically non-trivial property is further confirmed from the Laughlin-type quantized charge pumping. Adding to this, we propose a detection scheme allowing for the observation of the bosonic quantized charge pump using a feasible number of experimental snapshots. Our protocol provides a useful tool to realize and probe topological states of matter in quantum gases or photonic systems.

[1] M. Aidelsburger, M. Lohse, C. Schweizer, et al., Nature Physics 11, 162 (2015), [2] N. R. Cooper, J. Dalibard, and I. B. Spielman, Rev. Mod. Phys. 91, 015005 (2019), [3] T. Ozawa, H. M. Price, A. Amo, et al., Rev. Mod. Phys. 91, 015006 (2019).

Q 52.3 Thu 15:15 E001

Observation of a dissipative time crystal — •Phatthamon Kongkhambut[1], Hans Kessler[1], Jim Skulte[1], Ludwig Mathey[1], Jayson G. Cosme[2], and Andreas Hemmerich[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the small field decay rate ($\kappa/2\pi$ = 3.5 kHz), which is in the order of the recoil frequency ($\omega_{rec}/2\pi$ = 3.6 kHz). This leads to a unique situation where cavity field evolves with the same time scale as the atomic distribution. If the system is pumped transversally with a steady state light field, red detuned with respect to the atomic resonance, the Hepp-Lieb superradiant phase transition of the open Dicke is realized [1]. Starting in this self-ordered density wave phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetry broken states [2].

[1] J. Klinder et al., PNAS 112, 3290-3295 (2015).

[2] H. Keßler et al., PRL 127, 043602 (2021).

Q 52.4 Thu 15:30 E001

Time-periodic Lindblad master equations for quantum systems with engineered interactions and dissipation — •Simon B. Jäger, Jan Mathis Giesen, Christoph Dauer, Imke Schneider, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, D-67663, Kaiserslautern, Germany

Floquet engineering enables the creation of exotic and correlated many-body quantum states by using time-periodic driving. However, driving usually generates heat in the quantum system which can eventually lead to thermalization and loss of coherence on long timescales. A pathway to circumvent these detrimental effects can be engineered dissipation that drains away part of the introduced energy and stabilizes the quantum system far away from equilibrium. One possibility to engineer dissipation and also interactions within the quantum system is by coupling it to bosonic modes. We will show how one can quite generally eliminate the bosonic modes in such a scenario and achieve a Lindblad master equation which includes the mediated interactions and dissipation. We apply this procedure to the time-periodic dissipative Dicke model, a workhorse for the recently observed dissipative time crystals, and confirm its validity. Our results pave the ways towards the theoretical description of many-body quantum systems with mediated interaction and dissipation in presence of periodic driving.

Q 52.5 Thu 15:45 E001

Unveiling heating suppression regimes in a periodic driving Bose gas using a spacetime mapping — •Etienne Wamba[1,2], Axel Pelster[1], and James Anglin[1] — [1]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany — [2]Faculty of Engineering and Technology, University of Buea, Buea, Cameroon

We consider a Floquet-engineered model of many-body systems with rapid driving and map the evolutions of the model onto those of relatively slow processes. Such a mapping between rapid and slow evolutions allows us to investigate non-equilibrium many-body dynamics and examine how rapidly driven systems may avoid heating up, at least when mean-field theory is still valid. The fact that the fast time evolution of the system can be mapped exactly onto that of an almost static system suggests that rapid periodic driving does not automatically cause heating, because the system may have a kind of hidden adiabaticity.

Q 52.6 Thu 16:00 E001

Probing boundaries in interacting topological systems — •Marius Gächter, Zijie Zhu, Anne-Sophie Walter, Konrad Viebahn, and Tilman Esslinger — ETH, Zurich, Switzerland

Boundaries between topologically distinct materials give rise to gapless edge modes whose robustness against perturbations makes them promising candidates for technological applications. Therefore, it is crucial to gain a better understanding of topological edge states, especially regarding their response to interparticle interactions. In our experiment, we study quantised bulk Hall drifts of interacting ultracold fermions in the presence of a harmonic confinement. We discovered that quantised drifts halt and reverse in the opposite direction at the topological boundary which emerges due to the harmonic confinement. In the absence of interactions this reflection can be understood as a transfer of atoms between bands with opposite Chern numbers C = +1 and C = -1 via a gapless edge mode, in agreement with the bulk-edge correspondence. Interestingly, this reflection can be used to study the edge in an interacting system since a non-zero repulsive Hubbard U leads to the emergence of an additional edge in the system, which is purely interaction-induced.

Q 52.7 Thu 16:15 E001

Observation of edge states in topological Floquet systems — •Alexander Hesse[1,2], Christoph Braun[1,2,3], Raphaël Saint-Jalm[1,2], Johannes Arceri[1,2], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany —

[3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Floquet engineering, i.e., periodic modulation of a system's parameters, has proven as a powerful tool for the realization of quantum systems with exotic properties that have no static analog. In particular, the so-called anomalous Floquet phase displays topological properties even if the Chern number of the bulk band vanishes. [1]

Our experimental system consists of bosonic atoms in a periodically driven honeycomb lattice. Depending on the driving parameters, several out-of-equilibrium topological phases can be realized, including an anomalous phase. [2]

As the bulk-boundary correspondence relates the properties of the bulk bands to the number of topologically protected edge modes, special interest lies in studying the behavior of them. We are investigating the real-space evolution of a wavepacket close to the edge after the release from a tightly-focused optical tweezer. This way, we observe the chiral nature of the edge state, even in the anomalous Floquet phase, thereby directly revealing the topological nature of this phase.

[1] Rudner et al., Phys. Rev. X 3, 031005 (2013)
[2] Wintersperger et al., Nat. Phys. 16, 1058-1063 (2020)

Q 53: Single Quantum Emitters (joint session Q/QI)

Time: Thursday 14:30–16:30 Location: E214

Invited Talk Q 53.1 Thu 14:30 E214

Quantum information with atomic quantum metasurfaces and integrated nanophotonics — •Rivka Bekenstein for the SHIPTRAP-Collaboration — Hebrew University, Jerusalem, Israel

Quantum information processing with photonic qubits requires on-demand single photon sources, linear components, along with more advanced components such as quantum memories and deterministic nonlinearity to implement logic gates between photonic qubits. I will discuss two promising systems for generating and controlling photonic qubits. I will first present our fiber-coupled single-photon-source based on silicon-vacancy centers in nanophotonic cavity diamond. This source features high efficiency, purity, temporal control, and integrability. We have been able to demonstrate arbitrarily temporally shaped single photon pulses with high purity ($g2(0) = 0.0168$) and detection efficiency of 14.9. This achievement combined with previously demonstrated spin-photon gates and long-lived memory, enables on-demand generation of streams of correlated photons useful for one-way quantum computation. I will then present our quantum-metasurfaces-based quantum protocols for large-scale entanglement generation and quantum holography. These work build upon our recent analysis of quantum metasurfaces: two-dimensional atomic arrays which control light coherently by scattering.

Q 53.2 Thu 15:00 E214

Efficient High-Fidelity Flying Qubit Shaping — •Benedikt Tissot and Guido Burkard — Universität Konstanz

Single photon emission is the cornerstone of numerous quantum technologies, such as distributed quantum computing as well as several quantum internet and networking protocols. We find the upper limit for the photonic pulse emission efficiency for imperfect emitters and show a path forward to optimize the fidelity. The outlined theory for stimulated Raman emission is applicable to a wide range of physical systems including quantum dots, solid state defects, and trapped ions, as well as various parameter regimes in particular for any pulse duration. Furthermore, the mathematical idea to use input-output theory for pulses to absorb the dominant emission process into the coherent dynamics, followed by a quantum trajectory approach has great potential to study other physical systems.

Q 53.3 Thu 15:15 E214

Localized creation of yellow single photon emitting carbon complexes in hexagonal boron nitride — •Anand Kumar[1], Chanaprom Cholsuk[1], Askhan Zand[1], Mohammad Nasimuzzaman Mishuk[1], Tjorben Matthes[1], Falk Eilenberger[1], Sujin Suwanna[2], and Tobias Vogl[1] — [1]Abbe Center of Photonics, Institute of Applied Physics, Friedrich Schiller University Jena, 07745 Jena, Germany — [2]Mahidol University, Bangkok 10400, Thailand

Single-photon emitters in solid-state systems have received a lot of attention as building blocks for numerous quantum technology applications. Defect-based single-photon emitters in hexagonal boron nitride (hBN) stand out due to their optical and physical properties, such as room temperature operation and high single photon luminosity. However, the localized fabrication of these emitters in the crystal lattice is still not very well understood and thus the integration with optical and electronic platforms remains challenging. In the present work, we demonstrate the localized fabrication of emitters by electron beam irradiation using a scanning electron microscope with sub-micron lateral precision. Density functional theory calculations, coupled with experimentally observed emission lines at 575 nm show that the emitters are related to the presence of carbon-based defects, which are activated by the electron beam interaction. We also present results on correlating crystal structure properties and polarization dynamics. Our results indicate that these emitters have a high fabrication yield of identical emitters, which is a crucial advantage for the realization of quantum integrated devices.

Q 53.4 Thu 15:30 E214

Fingerprinting color centers in hexagonal boron nitride — •Chanaprom Cholsuk[1], Sujin Suwanna[2], and Tobias Vogl[1] — [1]Abbe Center of Photonics, Institute of Applied Physics, Friedrich-Schiller-University, Albert-Einstein-Straße 15, 07745 Jena — [2]Optical and Quantum Physics Laboratory, Department of Physics, Faculty of Science, Mahidol University, Bangkok, 10400, Thailand

Optical quantum technologies promise to revolutionize today's information processing and sensing. Crucial to many quantum applications are efficient sources of pure single photons. For a quantum emitter to be used in such application, or for coupling between different quantum systems, the optical emission wavelength of the quantum emitter needs to be tailored. Here, we use density functional theory (DFT) to calculate and manipulate the transition energy of fluorescent defects in the two-dimensional hexagonal boron nitride.

Our calculations feature the HSE06 functional which accurately predicts the electronic band structures of 267 different defects. Moreover, using strain-tuning we can tailor the optical transition energies of suitable quantum emitters to precisely match those of quantum technology applications. The complete photophysical properties of the emitters including spectrum profile, Huang-Rhys factor, radiative and non-radiative lifetime, quantum efficiency, and excitation and emission dipoles are also revealed. We thereby not only have a promising pathway for tailoring quantum emitters that can couple to other solid-state qubit systems but also get access to the complete fingerprint of the emitters for identifying the defect structure of the emitters.

Q 53.5 Thu 15:45 E214

Will a single two-level atom simultaneously scatter two photons? — •Luke Masters, Xinxin Hu, Martin Cordier, Gabriele Maron, Lucas Pache, Arno Rauschenbeutel, Max Schemmer, and Jürgen Volz — Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

The interaction of light with a single two-level emitter is the most fundamental process in quantum optics, and is key to many quantum applications. As a distinctive feature, two photons are never detected simultaneously in the light scattered by the emitter. This is commonly interpreted by saying that a single two-level quantum emitter can only absorb and emit single photons. However, it has been theoretically proposed that the photon anti-correlations can be thought to arise from quantum interference between two possible two-photon scattering amplitudes, which one refers to as coherent and incoherent. This picture is in stark contrast to the aforementioned one, in that it assumes that the atom even has two different mechanisms at its disposal to scatter two photons at the same time. Here, we validate the interference picture by experimentally verifying the 40-year-old conjecture that, by spectrally rejecting only the coherent component of the fluorescence light of a single two-level atom, the remaining light consists of photon pairs that have been simultaneously scattered by the atom. Our results offer fundamental insights into the quantum-mechanical interaction between light and matter and open up novel approaches for the generation of highly non-classical light fields.

Q 53.6 Thu 16:00 E214

Multi-channel waveguide-integrated single photon sources — •Chaiyasit Nenbangkaeo, Alexander Eich, Tobias Spiekermann, and Carsten Schuck — Institute of Physics, University of Münster, Germany

Integrated quantum photonic technology requires large numbers of single quantum emitters. While single-emitter systems have successfully been embedded into nanophotonic waveguides [1], the integration of larger numbers of single-photon sources into complex photonic circuits has remained a challenge. Here we show a novel approach that allows for simultaneously coupling single-photons from several independent colloidal quantum dots into tantalum pentoxide waveguides (Ta2O5). We employ a lithographic technique that probabilistically inserts quantum dots into a waveguide array and then deterministically remove multi-emitter systems until only a single-emitter per waveguide channel remains, thus achieving high-yield integration of single-photon sources across multiple nanophotonic channels. We demonstrate the feasibility of our method with autocorrelation measurements, showing anti-bunching of quantum dot photoluminescence for each individual channel. Our work paves the way for deterministically equipping photonic integrated circuits with large numbers of single-photon sources benefitting a wide range of applications in quantum technology.

[1] Eich, Alexander, et al., ACS Photonics 2022 9 (2), 551-558

Q 53.7 Thu 16:15 E214

Photoluminescence Excitation Characteristics of Color Centers in hBN at Room Temperature — •Pablo Tieben[1,2], Hiren Dobariya[2], Nora Bahrami[1,2], and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Gottfried Wilhelm Leibniz Universität, Hannover, Germany

In the rapidly developing field of quantum technologies single photons play an important role for a number of applications. Optically active color centers in hexagonal boron nitride (hBN) are of particular interest as they exhibit bright single photon emission over a broad range as well as narrow linewidths at and even well above room temperature. Furthermore, as a solid-state single photon source, these emitters can be reliably integrated into photonic circuits and thus offer a large advantage in terms of scalability. A dependency of the fluorescence emission of single emitters on the excitation wavelength has been observed recently, implying a more complex level structure. Systematic measurements of this dependency could reveal more information about the underlying energy levels and thus atomic structure of these defects. Particularly interesting are patterns in the separation between excited states for a classification of different types of emitters. We perform spectroscopic measurements while varying the excitation wavelength over a large range to gain further insight into their characteristic properties and energy level schemes. By analysis of the excitation spectrum of individual defects, we are extracting information on the distribution of energetic transitions across a large number of emitters.

Q 54: Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)

Time: Thursday 14:30–16:30 Location: F102

Q 54.1 Thu 14:30 F102

Cooling and control of the translational and rotational motion of a nano rotor — •Peter Barker[1], Antonio Pontin[1], Marko Toros[2], Hayden Fu[1], Tania Monteiro[1], Jonathan Gosling[1], and Markus Rademacher[1] — [1]University College London, UK — [2]University of Glasgow, Glasgow, UK

There has been significant interest in controlling the motional degrees of isolated, single nanoparticles, trapped within optical fields in high vacuum. They are seen as ideal candidates for exploring the limits of quantum mechanics in a new mass regime while they are also massive enough to be considered for future laboratory tests of the quantum nature of gravity. In this talk I will report on the control and cooling of all translational and rotational degrees of freedom of a nanoparticle trapped in an optical tweezer using cooling via coherent elliptic scattering where translational temperatures in the 100 μK range were reached, while temperatures as low as 5\,mK were attained in the librational degrees of freedom. I will also outline nanoparticle characterisation techniques based on the control and measurement of the librational and translational motion. This work opens up future applications in quantum science and the characterisation of single isolated nanoparticles free of interference from a substrate.

Q 54.2 Thu 14:45 F102

Polarization control of optically levitated nanoparticles — •Yanhui Hu, James Sabin, Mudassar Rashid, and James Millen — Department of Physics, King's College London, Strand, London

The optical control of anisotropic particles opens up applications in torque sensing and the study of rotational quantum mechanics. The angular modes of a levitated particle are markedly different from the linear modes, and new tools are required to achieve full control. In the Levitated Nanophysics Group at King's College London we work with nanofabricated silicon nanorods, which allow enhanced control over all degrees-of-freedom. We control the rotation of the nanorods through a recently discovered method for generating transverse optical vortices, which can be used to exert a large torque on an array of levitated nanoparticles. We also present a method to simultaneously cool all of the linear and angular modes of levitated, anisotropic particles, without the necessity for a delicate optical cavity.

Q 54.3 Thu 15:00 F102

Surface-induced decoherence and heating of charged rigid rotors — •Lukas Martinetz, Klaus Hornberger, and Benjamin A. Stickler — University of Duisburg-Essen

Levitating charged particles in ultrahigh vacuum provides a preeminent platform for quantum information processing, for quantum-enhanced force and torque sensing, for probing physics beyond the standard model, and for high-mass tests of the quantum superposition principle. Existing setups, ranging from single atomic ions to ion chains and crystals to charged molecules and nanoparticles, are crucially impacted by fluctuating electric fields emanating from nearby electrodes used to control the motion. In this article, we provide a theoretical toolbox for describing the rotational and translational quantum dynamics of charged nano- to microscale objects near metallic and dielectric surfaces, as characterized by macroscopic dielectric response functions. The resulting quantum master equations describe the coherent surface-particle interaction due to image charges and Casimir-Polder potentials as well as surface-induced decoherence and heating with the experimentally observed frequency and distance scaling. We explicitly evaluate the master equations for relevant setups, thereby providing the framework for describing and mitigating surface-induced decoherence as required in future quantum technological applications.

Q 54.4 Thu 15:15 F102

Decoherence-Free Rotational Degrees of Freedom for Quantum Applications — •Julen S. Pedernales, Francesco Cosco, and Martin B. Plenio — Institut für Theoretische Physik und IQST, Albert-Einstein-Allee 11, Universität Ulm, D-89081 Ulm, Germany

I will describe the use of spherical t-designs for the systematic construction of solids whose rotational degrees of freedom can be made robust to decoherence due to external fluctuating fields while simultaneously retaining their sensitivity to signals of interest. Specifically, the ratio of the signal phase accumulation rate from a nearby source to the decoherence rate caused by fluctuating fields from more distant sources can be incremented to any desired level by using increasingly complex shapes. This allows for the generation of long-lived macroscopic quantum superpositions of rotational degrees of freedom and the robust generation of entanglement between two or more such solids with applications in robust quantum sensing and precision metrology as well as quantum registers.

[1] J. S. Pedernales, F. Cosco, and M. B. Plenio, Phys. Rev. Lett. 125, 090501 (2020).

Q 54.5 Thu 15:30 F102

Group report: Precision spectroscopy and quantum information with trapped molecules — •Brandon Furey, Stefan Walser, Zhenlin Wu, Guanqun Mu, Rene Nardi, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck, Österreich

The quantum molecules group at the University of Innsbruck utilizes a range of innovative advances in molecular spectroscopy and quantum logic spectroscopy (QLS) to study molecular rovibrational structure and explore quantum information processing with trapped molecules. The efforts of our group are divided into three projects. The first is pump-probe recoil spectroscopy, where we measure the rovibrational population dynamics excited by a pump pulse by mapping them to the electronic state of an atomic ion via QLS. The second project investigates state-dependent force spectroscopy, where an optical tweezer generates a state-dependent force on a trapped molecule. Our third project is demonstrating superpositions of rotational states in a diatomic molecular ion built using stimulated Raman transitions driven by two beams from an optical frequency comb. This could pave the way for using quantum error correction to realize the use of trapped molecules for quantum information or memory. We are interested in creating the rotational superposition states that form the codewords of a truncated $Z_3 \subset Z_6$ linear rotor code. In order to demonstrate ultrafast light-matter interaction in our system, we have measured the photodissociation spectrum of $CaOH^+$ using an optical parametric amplifier.

Q 54.6 Thu 15:45 F102

From the rotation of a planar rigid rotor in electric fields to the semifinite-gap structure of an optical superlattice — •Marjan Mirahmadi[1], Bretislav Friedrich[1], Burkhard Schmidt[2], and Jesús Pérez-Ríos[1,3,4] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Weierstraß-Institut, Berlin, Germany — [3]Department of Physics, Stony Brook University, NY , USA — [4]Institute for Advanced Computational Science, Stony Brook University, NY, USA

We show that two seemingly unrelated problems – the trapping of an atom in a one-dimensional optical superlattice (OSL) formed by the interference of optical lattices whose spatial periods differ by a factor of two, and the libration of a polar polarizable planar rotor (PR) in combined electric and optical fields – have isomorphic Hamiltonians. It is possible to establish a map between the translations of atoms in the former system and the rotations of the rotor due to the coupling of its permanent and induced electric dipole moments to the external fields. The latter system belongs to the class of conditionally quasi-exactly solvable problems in quantum mechanics and exhibits intriguing spectral properties. We make use of our findings to explain the *semifinite-gap* band structure of the OSL. This band structure follows from the eigenenergies obtained as solutions of the Whittaker-Hill equation and their genuine and avoided crossings. Furthermore, the mapping makes it possible to establish correspondence between concepts, such as localization on the one hand and orientation/alignment on the other.

Q 54.7 Thu 16:00 F102

Experimental advances in the quest for perfect enantiomer-specific state control of cold molecules — •Juhyeon Lee[1], Johannes Bischoff[1], Alicia. O. Hernandez-Castillo[2], Boris Sartakov[1], Gerard Meijer[1], and Sandra Eibenberger-Arias[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Harvey Mudd College, Claremont, Callifornia, USA

Enantiomer-specific state transfer (ESST) was recently developed using tailored microwave fields [1]. This technique enables the population or depopulation of a rotational state of a chosen enantiomer, providing a way of quantum-controlled chiral separation. Recently, we have explored spectroscopic schemes to overcome previous limitations in the transfer efficiency of ESST: thermal population of the rotational levels and M_J degeneracy [2]. We improved the transfer efficiency up to 50%, and quantitatively studied ESST for the first time [3]. The experimental ESST efficiency was $\sim 20\%$ lower than theoretically expected. We attribute this partially to imperfections in the microwave polarizations and their respective orthogonality. We show a method to experimentally determine the polarization of microwave fields in-situ by quantitative analysis of molecular Rabi oscillations.

[1] S. Eibenberger, et al., Phys. Rev. Lett. 118, 123002 (2017)
[2] M. Leibscher, et al., Commun. Phys. 5, 1 (2022).
[3] J. H. Lee, et al., Phys. Rev. Lett. 128, 173001 (2022)

Q 54.8 Thu 16:15 F102

Photoelectron circular dichroism in rotationally excited mixtures — •Alexander Blech[1], Loren Greenman[2], Reinhard Dörner[3], and Christiane P. Koch[1] — [1]Fachbereich Physik, Freie Universität Berlin, Berlin, Germany — [2]Department of Physics, Kansas State University, Manhattan, KS, USA — [3]Institut für Kernphysik, Goethe-Universität, Frankfurt am Main, Germany

Gas phase experiments with chiral molecules may be carried out with randomly oriented molecules because there exist enantiomer-sensitive observables that survive orientational averaging. The strength of these observables is directly related to the enantiomeric excess and vanishes in the limit of a racemic mixture. Here we turn the perspective around and investigate whether it is possible to detect chiral signatures from racemic, but rotationally excited mixtures. We focus on photoelectron circular dichroism (PECD), which is the forward-backward asymmetry in the photoelectron angular distributions of chiral molecules upon ionization with circularly polarized light. Based on an analysis of the electric dipole response in rotationally excited molecular ensembles, we show that PECD can be observed in racemic mixtures by breaking the isotropy of the orientational distribution.

Q 55: Precision Spectroscopy of Atoms and Ions III (joint session A/Q)

Time: Thursday 14:30–16:30 Location: F303

Invited Talk Q 55.1 Thu 14:30 F303

Laser spectroscopy of the heaviest elements with the RADRIS technique — •Tom Kieck for the RADRIS-Collaboration — GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — Helmholtz-Institut Mainz, Germany

Exploring atomic and nuclear properties in the region of the heaviest elements through laser spectroscopy became possible with the RAdiation Detected Resonance Ionization Spectroscopy (RADRIS) technique at GSI. Fusion evaporation reaction products are separated from the primary beam in the velocity filter SHIP and then stopped in high-purity argon gas and collected onto a thin hafnium filament. Following re-evaporation, the released neutral atoms are probed by two-step resonance laser ionization. The resulting photo-ions are guided to a silicon detector for identification by their characteristic alpha radiation.

After a first observation and characterisation of an atomic ground-state transition in nobelium (Z = 102), the technique was applied to several nobelium and fermium isotopes. We present advancements of the RADRIS technique together with recent results from the FAIR phase-0 beamtime 2022 at GSI. The setup performance was optimised to achieve higher total efficiency, which is now up to 15%. Improved stability of the system allowed the search for atomic levels in lawrencium (Z = 103) for more than 400 hours. In addition, the short-lived isotope ^{251}No ($T_{1/2}$ = 0.8 s) was studied along with several fermium and californium isotopes. These results and further prospects will be discussed.

Q 55.2 Thu 15:00 F303

Collinear laser spectroscopy in $^{12,13}C^{4+}$ — •Patrick Müller[1], Phillip Imgram[1], Kristian König[1], Bernhard Maass[2], and Wilfried Nörtershäuser[1] — [1]Institut für Kernphysik, TU Darmstadt, Germany — [2]Argonne National Laboratory, Chicago, IL, USA

Laser spectroscopy has since long been used to determine differential nuclear charge radii $\delta\langle r^2\rangle$ for stable and short-lived isotopes. Recently, much effort was put in improved atomic structure calculations of helium-like systems to be able to extract absolute nuclear charge radii from $1s2s\,^3S_1 \rightarrow 1s2s\,^3P_J$ transition frequencies [1]. This can be used in light He-like ions, i. e., Be to N, in which the metastable state has sufficient lifetime to perform collinear laser spectroscopy and the transition wavelengths are in the laser accessible region.

We report on high-precision collinear laser spectroscopy measurements of the $1s2s\,^3S_1 \rightarrow 1s2s\,^3P_{0,1,2}$ transitions in $^{12,13}C^{4+}$ using the **Co**llinear **A**pparatus for **L**aser Spectroscopy and **A**pplied Physics (COALA) at the Institute of Nuclear Physics, TU Darmstadt. Although theory has not reached the accuracy to directly extract $\langle r^2\rangle$ in He-like systems with competitive uncertainty yet, mass-shift calculations between $^{12,13}C^{4+}$ will provide $\delta\langle r^2\rangle^{12,13}$ with very high precision in the conventional approach. The measured hyperfine structure of $^{13}C^{4+}$ which is modulated by significant hyperfine mixing will serve as another benchmark for testing atomic-structure theory. This project is supported by DFG (Project-ID 279384907 - SFB 1245).

[1] Yerokhin *et al.*, Phys. Rev. A **106**, 022815 (2022)

Q 55.3 Thu 15:15 F303

Laser photodetachment threshold spectroscopy at FLSR: first results — •Oliver Forstner[1,2], Vadim Gadelshin[3], Lothar Schmidt[4], Kurt Stiebing[4], Dominik Studer[3], and Klaus Wendt[3] — [1]Friedrich Schiller-Universtität Jena — [2]Helmholtz-Institut Jena — [3]Institut für Physik, Johannes Gutenberg-Universität Mainz — [4]Institut für Kernphysik, Goethe-Universität Frankfurt

The Frankfurt Low-energy Storage Ring (FLSR) is a room-temperature electrostatic storage ring, which can reduce the internal energy of stored ions almost to the ambient temperature, being suitable for laser photodetachment threshold (LPT) spectroscopy to determine the electron affinity of negatively charged ions. The latter play a key role in accelerator mass spectrometry (AMS): lasers can selectively neutralize undesired isobars, providing a purified beam of an isotope of interest. To extend the range of available AMS nuclides, it is necessary to identify neutralization schemes for unwanted atomic and molecular negative ions.

To achieve this goal, a source for negative ions was installed at FLSR and a compact laser lab was constructed guiding laser beams into FLSR. The laser setup is based on a tunable Ti:Sapphire laser pumped by a high repetition Nd:YAG laser. The neutralized ions are further downstream detected by a position sensitive MCP detector.

An overview of the setup and first results of precision spectroscopy of O^- will be presented. An outlook of further LPT studies will be given.

Q 55.4 Thu 15:30 F303

Laser spectroscopy of fermium across the deformed N=152 shell closure — •Elisabeth Rickert for the Fermium-Collaboration — GSI Darmstadt, Germany — JGU Mainz, Germany — HIM Mainz, Germany

The existence and stability of heavy nuclei is a forefront topic in nuclear physics. Modern laser spectroscopy techniques provide a unique tool to study nuclear shell effects by measuring isotope shifts to infer mean-square charge radii and hence deduce nuclear size and shape. Laser spectroscopy measurements of the isotope shift of an atomic transition of the actinide element fermium (Z=100) have been recently carried out covering isotopes across the N=152 shell closure. On-line and off-line laser spectroscopy experiments with direct and indirect production schemes and offline production methods were combined and methodologically pushed forward to measure isotope shifts in fermium isotopes. Previously inaccessible isotopes, short and long-lived, were covered, enabling experiments at atom-at-a-time quantities through newly developed detection concepts. Changes in the mean-square charge radii were extracted for the longest chain of isotopes investigated in the region of the heavy actinides revealing a discontinuity around the N=152 shell closure.

Q 55.5 Thu 15:45 F303

High-resolution spectroscopy of exotic silver with a cw OPO injection-seeded PDA — •Mitzi Urquiza-González[1], Volker Sonnenschein[1], Omorjit S. Khwairakpam[2], Bram van den Borne[3], Michael Heines[3], Ágota Koszorús[3], Katerina Chrysalidis[4], Ruben P. de Groote[3,5], Bruce Marsh[4], Korbinian Hens[1], and Klaus Wendt[6] for the CRIS-Collaboration — [1]Division HÜBNER Photonics, Hübner GmbH Co KG, Germany — [2]Istituto Nazionale di Fisica Nucleare LNL, Italy — [3]KU Leuven, Belgium — [4]CERN, Switzerland — [5]University of Jyväskylä, Finland — [6]Johannes Gutenberg Universität, Germany

Short-lived radioisotopes are of special interest for nuclear structure studies, as their characteristic provide valuable reference points for theoretical predictions far from stability. By using lasers, hyperfine transitions can be accessed, allowing direct measurement of nuclear observables. For such high-resolution spectroscopy, narrow-band pulsed lasers can be created by the pulsed amplification of a cw seed laser, keeping the amplifier's high power and short time profile whilst acquiring the seeder's spectral properties.

Spectroscopy on exotic Ag was performed at the CRIS experiment at CERN. A tunable cw single-mode OPO was employed as injection-seed for a two-stage pulsed dye amplifier. The hyperfine splitting of the ground-state $^2S_{1/2}$ to the level $^2P^O_{3/2}$ was measured and the hyperfine coupling constants were determined. For this work, ^{111,117}Ag are presented, showcasing this laser system's applicability for future high-resolution spectroscopy studies.

Q 55.6 Thu 16:00 F303

Hyperfine structures of neptunium — •Magdalena Kaja[1], Mitzi Urquiza-González[2], Felix Berg[1], Korbinian Hens[2], Tobias Reich[1], Matou Stemmler[1], Dominik Studer[1], Felix Weber[1], and Klaus Wendt[1] — [1]Johannes Gutenberg University, 55099 Mainz — [2]Hübner GmbH & Co. KG, Kassel, Germany

Neptunium is of major concern for the long-term safety of a high-level nuclear waste repository due to the long half-life of $2.1{\cdot}10^6$ years and the high radiotoxicity of its isotope ^{237}Np. In this context, trace analysis of environmental samples is of high relevance. Resonance ionization mass spectrometry (RIMS) is an excellent tool for selective and sensitive ultra-trace analysis of radionuclides but requires efficient excitation schemes and a suitable tracer for quantification. For isotope ratio determination, it is important to take into account the isotope-related effects in ionization schemes stemming from hyperfine structure (HFS) and isotope shift. Thus, new two-step excitation schemes for analysis of ^{237}Np and ^{239}Np as a tracer were identified and investigated.

Narrow bandwidth spectroscopy on ^{237}Np and ^{239}Np has been carried out at RISIKO mass separator using the specific PI-LIST laser ion source geometry together with an injection-locked seeded Ti:sa laser system. The latter has a spectral bandwidth of 20 MHz, while also providing a high repetition rate pulsed operation with the high-power density required for RIS. The HFS of the atomic ground-state transitions to the levels at 25 075.15 cm^{-1} and 25 277.63 cm^{-1} has been measured and hyperfine coupling constants for both isotopes as well as the isotope shift between ^{237}Np and ^{239}Np have been determined.

Q 55.7 Thu 16:15 F303

High-resolution laser spectroscopy on the isotopes $^{244-248}$Cm — •Nina Kneip[1], Felix Weber[2], Christoph E. Düllmann[2,3,4], Christian M. Marquardt[5], Christoph Mokry[2,3], Petra J. Panak[5], Sebastian Raeder[3,4], Jörg Runke[2,4], Dominik Studer[3], Clemens Walther[1], and Klaus Wendt[2] — [1]Leibniz University Hannover, 30060 Hannover — [2]Johannes Gutenberg University Mainz, 55099 Mainz — [3]Helmholtz Institute Mainz, 55099 Mainz — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt — [5]Karlsruhe Institute of Technology, 76131 Karlsruhe

The transuranium element curium ($Z = 96$) is one of the minor actinides present in spent nuclear fuel. It is produced during power reactor operation in a series of nuclear reactions from ^{238}U. The resonance ionization mass spectroscopy (RIMS) method was used at the RISIKO mass separator at Mainz University for off-line studies in the complex, highly dense atomic structure of Cm. Due to its high ionization efficiency and outstanding elemental selectivity, RIMS is an excellent tool for high-precision laser spectroscopy on these minuscule samples. The isotope shift was measured for the isotope chain $^{244-248}$Cm for two different energy levels with the electron configurations $5f^7 6d7s7p\,^9D_3$ and $5f^8 6d7s\,^9D_3$. The odd-A iostopes were present with only $10^{11} - 10^{12}$ atoms. A narrow band Ti:sapphire laser system was used for high-precision measurements specifically to resolve the hyperfine structures of ^{245,247}Cm with 15 hyperfine transitions each. Finally, the modified King plot was used to determine the missing mean square charge radius of ^{247}Cm.

Q 56: Quantum Gases: Fermions II

Time: Thursday 14:30–16:30 Location: F342

Q 56.1 Thu 14:30 F342

Hartree-Fock-Bogoliubov Variational Approach for BCS Superfluidity — •Nikolai Kaschewski and Axel Pelster — Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

The established theory for the BCS-BEC crossover is based on formulating the underlying many-body problem with the functional integral and on performing a Hubbard-Stratonovich transformation in the Bogoliubov channel [1,2]. A saddle-point approximation reveals then that the whole BCS-BEC crossover can only be described once Gaussian fluctuations around the saddle point are taken into account, which turns out to be numerically quite demanding.

Here we tackle this many-body problem from another point of view. To this end we work out a variational approach for the underlying Hamilton operator in canonical field quantization, which includes not only the Bogoliubov but also the Hartree and the Fock channel. We determine the first beyond mean-field corrections and compare their results for the density profiles in the BCS regime with the corresponding ones of the functional integral theory.

[1] C. A. Sá de Melo, M. Randeria, and J. R. Engelbrecht, Phys. Rev. Lett. **71**, 3202 (1993).

[2] J. R. Engelbrecht, M. Randeria, and C. A. R. Sá de Melo, Phys. Rev. B **55**, 15153 (1997).

Q 56.2 Thu 14:45 F342

Correlations in ultracold few-fermion systems revealed by matterwave microscopy — •Keerthan Subramanian, Sandra Brandstetter, Carl Heintze, Marvin Holten, Philipp Lunt, Luca Bayha, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Germany

The ability to image individual quantum particles has provided unprecedented access to microscopic correlations in few and many-body ultracold quantum systems. Recent advances in momentum space microscopy of continuous systems have revealed how Pauli blocking leads to fermionic antibunching and formation of cooper pairs in mesoscopic 2D fermi gases in the vicinity of a phase transition precursor.

Microscopy is inherently limited by optical resolution and this prevents direct imaging in position space when interparticle spacing is smaller than the resolution limit. Here we circumvent this limit by magnifying the many-body wavefunction using matterwave techniques prior to imaging the system thereby giving us access to particle correlations in position space. We use this technique to probe correlations in two paradigmatic models consisting of an equal or unequal number of spin components. A spin-balanced system shows a tendency towards short distance correlations with increasing interaction strengths. The opposite limit of a strongly interacting single impurity in a Fermi gas is also explored which is prepared using radio frequency transfer with motional state resolution. As the interaction strength in the system is increased the impurity preferentially binds to one of the majority atoms as revealed by higher-order correlations.

Q 56.3 Thu 15:00 F342

A mesoscopic fluid of 10 fermions — •Sandra Brandstetter, Philipp Lunt, Carl Heintze, Jonas Herkel, Marvin Holten, Keerthan Subramanian, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

A striking manifestation of collective behaviour is the emergence of hydrodynamics, the effective description of a system as a fluid. In addition to classical systems, hydrodynamic expansion has been observed in different many-body quantum systems, ranging from heavy ion collisions to ultracold quantum gases. However the emergence of hydrodynamics in the mesoscopic limit is still unexplored. Our cold atom experiment opens up new pathways starting from the smallest scales with deterministic control over the atom number and interaction strength. We observe the inversion of the initial aspect ratio after an interacting expansion - a signature of hydrodynamics - in a system comprised of only 10 particles.

We prepare few fermionic 6Li atoms in 2 different spin states in the ground state of an elliptical 2D trap. A sudden switch off of the confining potential in radial direction leads to an expansion in a 2D plane, which we perform at different interaction strengths. Our spin and single atom resolved imaging technique allows us to study correlations of any order between atoms. Two different matterwave magnification techniques provide access to momentum or real space at different times during the expansion, such that we can directly observe the inversion of the aspect ratio.

Q 56.4 Thu 15:15 F342

Full phase aberration correction - from the source to the atoms — •Paul Hill, Philipp Lunt, Johannes Reiter, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Heidelberg, Deutschland

Using light to engineer a broad class of potential landscapes for ultracold atoms has enabled numerous breakthroughs in the field of analog quantum simulation [1]. Especially, trapping and manipulation of individual particles requires light patterns of exquisite precision saturating the diffraction limit of high NA optics. Characterizing and eliminating wavefront errors in an optical setup is therefore a key factor for experimental success, but usually proves to be challenging or can only be done for parts of the setup.

Here, we present a method to measure the entirety of aberrations acquired in an optical setup with a Spatial Light Modulator (SLM), from the source plane to the atoms. This method relies on a type of Phase Shift Interferometry (PSI) [2] where we use a double well pattern sensitive to the phase aberrations present in the light path. Imaging the fluorescence signal of only 100 atoms trapped in this double well potential is sufficient to retrieve the relevant phase information, which is then used to cancel aberrations on the SLM. This allows critical components, including our vacuum window, to be mapped out that are usually inaccessible to aberration correction.

[1] W Hofstetter and T Qin 2018 J. Phys. B: At. Mol. Opt. Phys. 51 082001

[2] Philip Zupancic et al. Opt. Express 24, 13881-13893 (2016)

Q 56.5 Thu 15:30 F342

Dark state transport in a strongly interacting Fermi gas — Mohsen Talebi, •Simon Wili, Philipp Fabritius, Jeffrey Mohan, Meng-Zi Huang, and Tilman Esslinger — Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

Laser-induced coherence of atomic states can dramatically alter the properties of an atomic medium. For example, a three-level system in a lambda configuration can be transparent to a resonant laser when another laser drives the other resonance. This is known as electromagnetically induced transparency (EIT). Another feature is the so-called dark state: The system driven by two lasers has an eigenstate which is a superposition of the two ground states. While the amplitudes of this superposition, described by a mixing angle, depend on the optical fields, the energy of this state does not, hence it is dark. EIT and dark states have various applications, such as slow light, stimulated rapid adiabatic passage (STIRAP), and photonic quantum memory. Here we study transport of a Fermi gas with two strongly-interacting spins, one of which is subject to an auxiliary lambda system. We create a particle current flowing through a one-dimensional channel connecting two superfluid reservoirs. A localized laser beam addressing a transition of the lambda system in the channel suppresses fast particle transport, while a second beam fulfilling the EIT condition can revive the fast transport. Hence we demonstrate a current that comprises a dark state for the first time in a strongly-interacting fermionic system. As in our system the pairing interaction depends on the mixing angle, this work paves the way for local and temporal engineering of fermionic pairing.

Q 56.6 Thu 15:45 F342

Exploring doped antiferromagnets with a Quantum Gas Microscope — Petar Bojovic[1,2], Sarah Hirthe[1,2], Thomas Chalopin[1,2], Dominik Bourgund[1,2], Si Wang[1,2], Timon Hilker[1,2], and •Immanuel Bloch[1,2,3] — [1]Max Planck Institute of Quantum Optics — [2]Munich Center for Quantum Science and Technology — [3]Ludwig Maximilian University

We use our quantum gas microscope of fermionic ^{6}Li atoms loaded into the optical lattices to realize and study magnetic phases of the Fermi-Hubbard model with single-site spin and density resolution. In this talk, I will present our recent implementation of highly stable and tunable optical bichromatic superlattices, which provide the flexibility to test promising cooling protocol and reach novel phases of matter. I will furthermore discuss how we use a digital micromirror device (DMD) for potential shaping on individual sites and create tailored geometries [1, 2]. In such microscopically engineered systems, we can investigate interaction mechanisms in hole- or doublon- doped antiferromagnets and probe the formation of magnetically induced bound pairs among dopants.

[1] P. Sompet, S. Hirthe, D. Bourgund et al., Nature 606, 484-488 (2022)
[2] S. Hirthe et al., arXiv: 2203.10027 (2022)

Q 56.7 Thu 16:00 F342

Feshbach molecules in an optical orbital lattice — •Max Hachmann, Yann Kiefer, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We experimentally study strongly interacting degenerate Fermi gases exposed to an optical lattice. Previous studies focussed on the case, where only the lowest Bloch band is populated, such that the orbital degree of freedom is excluded. We report our experimental findings studying ultracold Feshbach molecules of fermionic 40K atoms selectively prepared in the second Bloch band of a bipartite optical square lattice, covering a wide range of interaction strengths including the regime of unitarity. Binding energies and band relaxation dynamics are measured by means of a method resembling mass spectrometry. The longest lifetimes arise for strongly interacting Feshbach molecules at the onset of unitarity with values around 300ms for the lowest band and 100ms for the second band. In the case of strong confinement in a deep lattice potential, we observe bound dimers also for negative values of the s-wave scattering length, extending previous findings for molecules in the lowest band. Our work prepares the stage for orbital BEC-BCS crossover physics.

Q 56.8 Thu 16:15 F342

Thermometry for trapped fermionic atoms in the BCS limit — •Sejung Yong, Sian Barbosa, Artur Widera, and Axel Pelster — Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

Measuring the temperature of an interacting fermionic cloud of atoms in the BCS limit represents a delicate task. In the literature temperature measurements have so far been only suggested in an indirect way, where one sweeps isentropically from the BCS to the BEC limit. Instead we suggest here a direct thermometry, which relies on measuring the column density and comparing the obtained data with a Hartree-Fock-Bogoliubov mean-field theory combined with a local density approximation. In case of an attractive interaction between two-components of ^{6}Li atoms trapped in a tri-axial harmonic confinement we show that minimizing the error within such an experiment-theory collaboration turns out to be a reasonable criterion for determining the temperature. The findings are discussed in view of various possible sources of errors.

Q 57: Quantum Networks II (joint session QI/Q)

Time: Thursday 14:30–16:30 Location: F428

Q 57.1 Thu 14:30 F428

A quantum interface between NV center matter qubits and Thulium rare-earth ion quantum memory compatible light — •M.C. Roehsner[1], M. Iuliano[1], A.J. Stolk[1], M. Sholkina[1], N. Alfasi[1], T. Chakraborty[1], W. Tittel[1,2], and R. Hanson[1] — [1]QuTech & Kavli Institute of Nanoscience, Delft University of Technology — [2]Department of Applied Physics, University of Geneva & Schaffhausen Institute of Technology, Geneva

Quantum networks promise to enable applications ranging from secure communication to fundamentally new kinds of computation. However, the individual components of quantum networks may be realized with different kinds of physical systems, requiring specialized interfaces. Here we present our work towards interfacing a diamond Nitrogen Vacancy (NV) center, well suited as a local quantum processing network node [1], with light compatible with Tm-based rare-earth ion quantum memories, well suited for long-range quantum repeaters [2]. We demonstrate two-photon quantum interference between photons emitted from an NV center with weak coherent light resonant with a Tm-based memory, probing the indistinguishability of the photons created by these disparate sources, using a low noise two-step quantum frequency conversion process. Furthermore, we present latest results towards teleporting a memory-compatible time-bin qubits into the NV center. With this quantum interface between different physical systems, we aim to bridge the gap between two key network components.

[1] Hermans, S.L.N. et al. Nature 605 (2022) [2] Davidson J.H. et al. Phys. Rev. A 101 (2020)

Q 57.2 Thu 14:45 F428

Space-borne quantum memories for global quantum networking — •Mustafa Gündoğan[1], Jasminder Sidhu[2], Daniel Oi[1], and Markus Krutzik[1] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]University of Strathclyde

Exponential losses in optical fibres limit the transmission of quantum information to around few hundred kilometres. Quantum repeaters based on the heralded storage of entangled photon pairs were proposed to increase this direct transmission limit. Nevertheless, these architectures are still limited to around few thousand kilometres.

In this talk I will present our proposal for placing quantum memories on board orbiting satellites to enable quantum networking at a truly global scale. The first idea relies on building a network of satellites equipped with QM with storage times of <1s. One can then create a quantum repeater in space to cover global distances [1]. The second idea is to use a single orbiting satellite equipped with two QMs: one with long (∼h) and the other short (∼ms) storage times. Quantum information is then shuttled across the globe in a time-delayed quantum repeater fashion. This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant number 50WM2055.

[1] M. Gündoğan *et. al.*, npj Quantum Information **7**, 128 (2021)

Q 57.3 Thu 15:00 F428

Towards remote entanglement of single erbium dopants — •Alexander Ulanowski[1], Fabian Salamon[1], Benjamin Merkel[1], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

In a future quantum internet, coherent emitters will exchange quantum states over global distances, preferably using optical fibers to establish entanglement between remote spins. To this end, erbium dopants are a promising platform due to the optical transition in the telecom band enabling low-loss distribution of photons. To realize an efficient spin-photon interface for single dopants, we embed a thin erbium doped crystal into a tuneable high-finesse Fabry-Perot resonator. In our experiment we achieve up to 110-fold Purcell enhancement while the coherence is preserved up to the lifetime limit by avoiding proximal interfaces [1]. Using spectral multiplexing gives us access to hundreds of individual dopants which exhibit a low spectral diffusion (< 0.2 MHz) currently limited by the nuclear spin bath [2]. To further improve the spectral stability and enable entanglement generation via photon interference, we thus investigate spin-free ^{29}Si crystals as a possible host material [3]. Furthermore, we expect considerable stability improvement by applying real-time feedback on the emitter frequency. This opens perspectives for long-distance entanglement at kilohertz rates.

[1] B. Merkel et al., Phys. Rev. X 10, 041025 (2020).
[2] A. Ulanowski et al., Sci. Adv. 8, eabo4538 (2022).
[3] Y. Liu et al., Journ. Cryst. Growth, 126733 (2022).

Q 57.4 Thu 15:15 F428

Hong-Ou-Mandel Interference in LNOI — •Silia Babel, Laura Bollmers, Marcello Massaro, Kai Hong Luo, Michael Stefszky, Federico Pegoraro, Philip Held, Harald Herrmann, Christof Eigner, Benjamin Brecht, Laura Padberg, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

A quantum computer can be built solely using single photons sources,

linear optics and single photon detectors. For the realisation of a photonic quantum computer, a particular interest has been devoted to the study of integrated networks since these offer many advantages such as stability, the possibility of compact devices and high efficiency, and thus provide scalability. The foundation of these integrated networks are directional couplers and interference between single photons.
A interesting platform for this purpose is Lithium Niobate on Insulator (LNOI) since it combines the advantages of conventional lithium niobate, such as a wide transparency window and high nonlinear coefficients, with a high integration density. To show that this material is suited for the realisation of integrated quantum networks, we demonstrate Hong-Ou-Mandel interference (HOMI) of telecom photons on a balanced directional coupler. We designed and fabricated the coupler in-house and achieve a raw HOMI visibility of (93.5±0.7)%. Our work demonstrates a crucial building block for integrated quantum networks based on LNOI.

Q 57.5 Thu 15:30 F428

Portable warm vapor memory — •Martin Jutisz[1], Elisa Da Ros[1], Alexander Erl[2,3], Leon Messner[1,3], Luisa Esguerra[3,2], Janik Wolters[3,2], Mustafa Gündoğan[1], and Markus Krutzik[1,4] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany — [3]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany — [4]Ferdinand-Braun-Institut (FBH), Berlin, Germany

Warm vapor memories have seen significant progress in terms of efficiency and storage time in recent years. Their low complexity makes them a promising candidate for operation in non-lab environments including space-based applications. As necessary element of quantum repeaters, memories operating in space could advance global quantum communication networks [1].

We will present the overall status of integration and test of a portable rack-mounted system. The implementation of the optical memory is based on electromagnetically induced transparency on the Cesium D1 line at 894 nm. Three lasers are frequency stabilized to provide pump, signal and control pulses. Automated locking is realized via a FPGA-based tool for laser frequency stabilization. The storage platform is provided by a heated Cesium vapour cell in a three-layer magnetic shield. Possibilities of micro integration are also being investigated.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWK) under grant number 50RP2090.

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)

Q 57.6 Thu 15:45 F428

Single erbium dopants in nanophotonic resonators — •Jakob Pforr[1,2], Andreas Gritsch[1,2], Alexander Ulanowski[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

Single erbium dopants in nanophotonic resonators are promising for the realization of quantum networks owing to their outstanding optical and spin coherence properties [1] and their large spectral multiplexing potential [2]. Previous experiments used yttrium-based host crystals, in which erbium is integrated in well-defined sites. However, these crystals are not compatible with established nanofabrication techniques, which hinders scalable integration into on-chip photonic circuits. To address this challenge, we have spectroscopically studied ensembles of erbium dopants in silicon nanostructures. After optimizing the erbium implantation procedure, we have observed two well-defined lattice sites with narrow inhomogeneous broadening (< 1 GHz), narrow homogeneous linewidths (< 0.01 MHz) and optical lifetimes of 0.2 ms [3]. In one-dimensional photonic crystal resonators ($Q > 10^4$, $V \sim \lambda^3$), we observe single dopants with a 60-fold Purcell-enhanced emission. We will present studies of the optical coherence, spectral diffusion, spin properties and spectral multiplexing capability of these devices.

References:
[1] Merkel et. al. 2020. PRX 10(4): 041025.
[2] Ulanowski et. al. 2021. SciAdv 8(43): eabo4538.
[3] Gritsch et. al. 2021. PRX 12(4): 041009.

Q 57.7 Thu 16:00 F428

High fidelity single-shot readout of telecom emitters in a Fabry-Perot resonator — •Fabian Salamon[1,2], Alexander Ulanowski[1,2], Johannes Früh[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

Erbium dopants are prime candidates for the realisation of extended quantum networks, as they combine second-long ground state coherence with a coherent optical transition in the telecommunication window, where loss in optical fibers is minimal [1].

To implement quantum information processing in this novel platform, we perform single-shot readout of the spin state by resonantly driving the optical transition and detecting the subsequently emitted photons. We overcome the challenge that erbium lacks a cycling transition [2] by using a Fabry-Perot resonator with a narrow linewidth (50 MHz) [3] in order to selectively enhance the readout transition.

Combined with our recent advances in spectral multiplexing [4], the successful implementation of high-fidelity single-shot readout is a key step towards high-rate entanglement of distant erbium dopants.

[1] A. Reiserer, arXiv:2205.15380 (2022).
[2] M. Raha et al., Nat. Commun. 11, 1605 (2020).
[3] B. Merkel, A. Ulanowski & A. Reiserer, Phys. Rev. X 10, 041025 (2020).
[4] A. Ulanowski, B. Merkel & A. Reiserer, Sci. Adv. 8, eabo4538 (2022).

Q 57.8 Thu 16:15 F428

Electromagnetically Induced Transparency in hollow-core light-cages: Simulation tool and experimental preparation — •Dominik Ritter[1], Esteban Gómez-López[1], Jisoo Kim[2], Markus Schmidt[2,4], Harald Kübler[3], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Leibniz Institute of Photonic Technology, 07702 Jena, Germany — [3]University of Stuttgart, 70569 Stuttgart, Germany — [4]Otto Schott Institute of Material Research, 07743 Jena, Germany

Quantum repeaters and memories are needed to overcome efficiently the losses of long-distance quantum networks [1]. A promising system to host a quantum memory is atomic vapours, which can be enhanced with guiding photonic structures [2].

We will present a simulation program and experimental measurements for enhanced light matter interaction in hollow-core light-cages (LC) inside a warm cesium vapor cell. The program calculates the absorption spectra of alkali vapors under Electromagnetically Induced Transparency (EIT). Propagation of light pulses through the bare atomic vapor and the LC are simulated, where a linear loss model is assumed. This use of the LC would lead towards controllable time delay of photons in an easy to use and easy to implement device and eventually a reliable platform for a quantum memory for single photons using the EIT-storage scheme [3].

[1] P. v. Loock et al., Adv. Quantum Technol. 3, 1900141 (2020). [2] K. F. Reim et al., Phys. Rev. Lett. 107, 053603 (2011). [3] J. Wolters et al., Phys. Rev. Lett. 119, 060502 (2017).

Q 58: Quantum Optics with Photons I

Time: Thursday 14:30–16:30 Location: F442

Q 58.1 Thu 14:30 F442

Improving the Phase Sensitivity of $SU(1,1)$ Interferometers by Phase Matching Compensation — •Dennis Scharwald and Polina Sharapova — Paderborn University, Department of Physics, Warburger Str. 100, D-33098 Paderborn, Germany

Improving the phase sensitivity of interferometers is a central challenge in quantum optics. Using coherent light, the lower limit for the sensitivity is given by the shot noise limit (SNL), while the quantum mechanical lower bound for this sensitivity is given by the Heisenberg limit. One way of surpassing the shot noise limit is using $SU(1,1)$ interferometers, which consist of two PDC sections. Between these sections pump, signal and idler photons experience some relative phase shift. [1] In our work, we extend the approach of integro-differential equations for the description of the PDC process derived in Ref. [2] to a certain kind of configuration where the PDC radiation generated by a single crystal is focussed back into a PDC section after experiencing the phase shift. We show numerically that using this setup, the phase sensitivity of the interferometer can be improved below the shot noise limit easier than using an SU(1, 1) interferometer without such kind of compensation.

[1] M. Manceau *et al.*, New J. Phys. **19**, 013014 (2017)
[2] P. R. Sharapova *et al.*, Phys. Rev. Research **2**, 013371 (2020)

Q 58.2 Thu 14:45 F442

Quantum characterization of superconducting detectors — •Timon Schapeler and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

Single-photon detectors, especially based on superconductivity are indispensable for most quantum applications, which makes characterizing them necessary to ensure proper operation. We show a characterization of superconducting nanowire single-photon detector arrays using quantum detector tomography. We quantify the photon-number-resolving ability through the purity of the detection outcomes. Additionally, we investigate the spectral response of a detector for possible spectroscopic applications.

Q 58.3 Thu 15:00 F442

Optical quantum tomography in the time domain — •Emanuel Hubenschmid[1], Thiago Guedes[2], and Guido Burkard[1] — [1]Universität Konstanz, 78467 Konstanz, Deutschland — [2]Forschungszentrum Jülich, 52428 Jülich, Deutschland

Electro-optic sampling presents a powerful tool to sample the waveform of a mid-infrared pulse in the time domain by measuring the effect a nonlinear interaction of the sampled mid-infrared pulse has on an ultrabroadband near-infrared pulse. Recent experiments applied this technique to sample the electric field fluctuation of the squeezed vacuum [Nature 541, 376 (2017)] on a sub-cycle scale. However, a full quantum tomography scheme in the time domain is still missing. Here we present a theoretical description of a possible electro-optic-based quantum tomography scheme with sub-cycle resolution. By combining novel theoretical tools to describe the interaction of the sampled pulse and an ultrabroadband near-infrared pump pulse in the nonlinear crystal [Phys. Rev. D 105, 056023 (2022)] and of quantum tomography with continuous wave-driven electro-optic sampling [Phys. Rev. A 106, 043713 (2022)], we calculate the probability distribution of our tomography schemes signal depending on the time delay between the sample and near-infrared pulse. Furthermore, we analyze the noise of the signal and describe how to reduce the contribution due to the broadness of the pump pulse. Combining these results, we describe how to reconstruct an arbitrary quantum state and its waveform, without any post-processing in the frequency domain and thereby paving the way towards quantum tomography in the time domain.

Q 58.4 Thu 15:15 F442

Measurement of two-point spectral correlation functions of pulsed quantum states of light — •Abhinandan Bhattacharjee, Patrick Folge, Laura Serino, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Coherence theory is an established research area for characterizing statistical randomness in an optical field. Typically, coherence is quantified through a two-point correlation function. This is routinely measured in spatial and temporal domains. One can also consider spectral coherence, however, the measurement of spectral two-point correlation function becomes challenging because interferometric techniques generally require high-intensity input fields and reconstruction algorithms do not work well for arbitrary spectral shapes.

Recently, the emergence of the quantum pulse gate (QPG), a frequency up-conversion process, has enabled the projection of an input field onto any desired spectral mode with high fidelity, including in the single photon regime. This device therefore overcomes the challenges of measuring spectral coherence. We propose an interferometric scheme that uses a QPG to project a classical or quantum state of light field onto a superposition of two spectral bins and obtains the two-point correlation function by measuring the intensity of the up-converted field as a function of the bin separation. In the context of parametric down-conversion, the spectral coherence measurement of only one of the arms certifies the spectral entanglement between two outputs.

Q 58.5 Thu 15:30 F442

Bi-photon correlation time measurements with a two-colour broadband SU(1,1) interferometer — •Franz Roeder, Michael Stefszky, René Pollmann, Kai Hong Luo, Matteo Santandrea, Victor Quiring, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

SU(1,1) interferometers have lately been used for several applications such as achieving super-sensitivity for quantum metrology or enabling spectroscopy and imaging with undetected photons. So far, most of the developed interferometers are based on parametric down-conversion (PDC) from bulk crystals, limiting the brightness of the sources as well as integrability. Furthermore, only spectral or temporal interferograms have been investigated so far.

Here, we demonstrate spectral and temporal interferometry using a SU(1,1) interferometer based on ultra-broadband, non-degenerate dispersion-engineered parametric down-conversion in nonlinear waveguides. These PDC sources exhibit strong frequency correlations and, simultaneously, sub-100 fs photon-photon correlation times. Measuring spectral and temporal interferograms simultaneously allows us to extract the ultra-short biphoton correlation time of our source, a task that has been challenging until now. Knowledge about this quantity is essential for further applications such as entangled two-photon absorption.

Q 58.6 Thu 15:45 F442

Terahertz sensing with undetected photons — •Mirco Kutas[1,2], Björn Haase[1,2], Jens Klier[1], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Fraunhofer Institute for Industrial Mathematicutes ITWM, Fraunhofer-Platz 1, 67663 Kaiserslarn — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern

Today, terahertz applications are widely used in industry as well as scientific research. Although the used components have undergone a tremendous development in recent decades, detection of terahertz radiation is still subject of current investigation. By using a quantum-optical measurement concept, we demonstrate a novel approach to detect phase-sensitive terahertz information. With this concept, it is possible to transfer the terahertz photon properties after interaction with a sample to visible photons. As a result, detection can be realized by easily accessible and highly developed silicon-based detectors without the need of cooling or expensive equipment. We report on the demonstration of quantum sensing and spectroscopy in the terahertz frequency range by only detecting visible light.

Q 58.7 Thu 16:00 F442

Remote Imaging in a Three Atom System — •Manuel Bojer[1], Jörg Evers[2], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

We study a system consisting of three identical two-level atoms where two atoms are assumed to be close to each other such that they interact via the dipole-dipole interaction while the third atom is located at a distance $d \gg \lambda$, with λ the atomic transition wavelength. Although the distant third atom does not directly interact with the collective two-atom subsystem, it can be used to alter the total system's spontaneous emission properties via measurement-induced entanglement. We present a detection scheme for which Glauber's third-order photon correlation function displays an oscillatory behavior in time, with a frequency determined by the coherent coupling parameter of the dipole-dipole interaction between the first two atoms. This parameter crucially depends on the two-atom separation allowing to resolve the distance between the two adjacent atoms with sub-Abbe resolution.

Q 58.8 Thu 16:15 F442

Phase-quadrature quantum imaging with undetected light — •Björn Haase[1,2], Joshua Hennig[1,2], Mirco Kutas[1,2], Erik Waller[1], Julian Hering[2], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Fraunhofer Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern

The use of nonlinear interferometers allows sensing with undetected photons. The corresponding experiments base on biphotons that are generated by spontaneous parametric down-conversion. They enable the transfer of spectral properties from one spectral range that is usually hard to investigate to photons from another spectral region easier to observe. By detecting these signal photons, the interaction of a sample with the idler light can be investigated. So far, the sample's information in terms of both phase and transmittance is received by measuring the corresponding interferogram, which is achieved by multiple recordings with phase changes in between. On this conference, I will present an alternative phase-quadrature approach with a nonlinear interferometer used for imaging with undetected light in the NIR range. With this development, in which we use wave plates and a polarizing beam splitter, we are able to obtain both the phase and visibility with one single image acquisition without the requirement to change optical paths or phases. Thus, with the reduced measurement duration it becomes possible to observe dynamic processes like the drying of an isopropanol film with this kind of nonlinear interferometer.

Q 59: Poster IV

Time: Thursday 16:30–19:00 Location: Empore Lichthof

Q 59.1 Thu 16:30 Empore Lichthof

State-dependent force spectroscopy for trapped ions — •Stefan Walser, Zhenlin Wu, René Nardi, Guanqun Mu, Brandon Furey, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck, Austria

Optical trapping and laser cooling are techniques that founded a revolution of quantum experiments in which atoms and molecules are manipulated using optical forces induced by laser light. A particularly useful technique are optical tweezers which are routinely used in many scientific disciplines. Certain trapped ions are an excellent basis for high precision spectroscopic experiments due to the available electronic structure for state preparation and read-out at the single atom level. Within this project we aim to combine state-dependent optical tweezers to manipulate the motional modes of an ion crystal with quantum logic spectroscopy. We plan to co-trap a well controllable $^{40}Ca^{+}$ logic ion with a molecular ion of interest which is inaccessible to the standard spectroscopic techniques in ion traps. Applying a state-dependent force on the molecular ion using an optical tweezer, the overall trapping potential is modified. This consequently changes the frequency of the ion's common motional mode. That frequency shift can be measured via the logic ion. Thereby we realize a quantum non-demolition measurement of the molecule's internal vibrational and rotational states. We hope that this project will facilitate the nondestructive state detection of molecules with the outlook of providing a basis for a compact spectrometer for atomic and molecular systems.

Q 59.2 Thu 16:30 Empore Lichthof

Decoherence of Rigid Rotors due to Emission of Thermal Radiation — •Jonas Schäfer, Benjamin A. Stickler, and Klaus Hornberger — Faculty of Physics, University of Duisburg-Essen, Duisburg

Recent advances in the control of levitated nanoparticles open the door for fundamental tests and sensing applications exploiting their rotational degrees of freedom [1]. This poster presents the quantum master equation of rotational and translational decoherence of internally hot dielectric particles of arbitrary size and shape emitting thermal radiation. We find that even highly symmetric objects, such as spheres, exhibit orientational decoherence since the internal excitations sourcing the emitted fields break the symmetry of the particle. We quantify the resulting decoherence rates for upcoming experiments with nanoscale to microscale objects.

[1] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589-597 (2021)

Q 59.3 Thu 16:30 Empore Lichthof

Dynamics of superconducting microscale rotors — •Fynn Köller, Klaus Hornberger, and Benjamin A. Stickler — University of Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany

The rotation dynamics of magnetizable objects can be affected strongly by spin-rotational coupling since their internal magnetization field contributes to their total angular momentum. Starting from the classical equations of motion, this poster will derive the Hamiltonian of a superconducting rotor of ellipsoidal shape levitated diamagnetically in a magnetostatic quadrupole field. We will discuss how signatures of strong spin-rotational coupling might become observable in upcoming experiments in the field of levitated nanomechanics and discuss the prospects for magnetic-field sensing.

Q 59.4 Thu 16:30 Empore Lichthof

Quantum interference of electrically trapped particles — •Eric van den Bosch, Lukas Martinetz, Klaus Hornberger, and Benjamin A. Stickler — University Duisburg-Essen, Duisburg, Germany

Orientational quantum revivals are a pronounced quantum interference effect caused by the fundamental quantization of angular momentum [1]. This poster will show how this quantum effect can be observed with electrically charged nanorotors suspended in the time-dependent fields of quadrupole ion traps. We will propose a concrete setup and discuss under what conditions coherence times on the order of a few seconds are realistically achievable.

[1] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589 (2021)

Q 59.5 Thu 16:30 Empore Lichthof

Navigation via a Gimbal-Stabilized Quantum Accelerometer — •Mouine Abidi[1], Philipp Barbey[1], Yueyang Zou[1], Ann Sabu[1], Dennis Schlippert[1], Christian Schubert[2,1], Ernst. M Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

Inertial navigation and positioning systems are the basis for controlling vehicles such as aircraft, ships, or satellites. However classical inertial sensors suffer from device-dependent drifts and require GNSS corrections.

Satellite navigation (GNSS) possesses inherent limitations. Its signals are prone to natural or human-made interference. Besides no GNSS signal in some areas.

Hybrid quantum navigation, based on the combination of classical Inertial Measurement Units with quantum sensors based on atom interferometry are a serious candidate for a new technology that meets today's requirements for inertial navigation.

We present our latest activities to transfer a complex laboratory-based device to a robust and compact measurement unit that can be used in a dynamic environment to subtract the drifts of classical devices. Using a new laser system design with the latest developed electronics along with the implementation of new optics schemes and commercial compact vacuum system.

Q 59.6 Thu 16:30 Empore Lichthof

T^4-Atom Interferometer Sensitive to Angular Acceleration — •Bernd Konrad and Maxim Efremov — German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

Nowadays, matter-wave interferometry has become a powerful technique for measuring acceleration, gravity gradient, and constant rotation with enormous precision [1]. Here, we explore atom interferometer which is highly sensitive to unknown constant angular acceleration $\dot{\Omega}$. By modeling rotation with fixed axis and constant angular acceleration with time-dependent angular velocity $\vec{\Omega}(t) = (\Omega_0 + \dot{\Omega}t)\vec{e}_\Omega$, where Ω_0 is its initial value, we employ atom-interferometric scheme based on a sequence $\pi/2 - \pi - \pi - \pi - \pi/2$ of five Raman laser pulses [2]. For a small enough Ω_0, we have found that the interferometer has a very high contrast, $C \approx 1$, more precisely it is reduced only by a correction scaling with the sixth order of Ω_0, that is $C = 1 + \mathcal{O}\left(\Omega_0^6\right)$. On the other hand, the leading term of the interferometer phase is linearly proportional to the angular acceleration $\dot{\Omega}$ and scales as T^4, namely $\varphi \propto \dot{\Omega}T^4 + \mathcal{O}\left(\Omega_0^3\right)$, where T is the total interferometer time. In addition, we have investigated the feasibility of the proposed scheme for the typical ground- and space-based configurations, such as a rotating platform on earth and satellites.

[1] G.M. Tino and M.A. Kasevich (Eds.), Atom Interferometry (IOS Press, Amsterdam, 2014)
[2] K.-P. Marzlin and J. Audretsch, Phys. Rev. A **53**, 312 (1996)

Q 59.7 Thu 16:30 Empore Lichthof

The Very Long Baseline Atom Interferometry facility for high precision gravity measurement — •Ali Lezeik[1], Mario Montero[1], Constantin Stojkovic[1], Klaus Zipfel[1], Dorothee Tell[1], Vishu Gupta[1], Henning Albers[1], Sebastian Bode[1], Jonas Klussmeyer[1], Ernst Rasel[1], Christian Schubert[1,2], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover- Insititut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik

Matter-wave interferometry is a sequence of light pulses used to manipulate an ensemble of ultracold atoms and let them interfere. This interference pattern contains rich information about the intertial forces acting on the atoms like the gravitational acceleration, making atom interferometers useful devices for metrological applications and testing fundamental physics. Their sensitivity depends on several factors one of which being the freefall time. A second-long free fall of the atoms allows to reach acceleration sensitivities of 1 nm/s^2, comparable to the best classical gravimeters. In addition, excellent control over the environment and a high number of atoms in the ensemble is necessary to reduce systematic effects and enhance the signal to noise ratio. The 15 m high Very Long Baseline Atom Interferometry facility (VLBAI) aims for sub nm/s^2 gravity measurement sensitivities. We present the current status of the VLBAI and outline the distinguishing aspects of the facility that includes a dual source chamber of ytterbium and rubidium, a 10 m long UHV baseline magnetically shielded to below 1.5 nT/m, and a seismic attentuation system for intertial referencing.

Q 59.8 Thu 16:30 Empore Lichthof

Dark Energy search using atom interferometry in microgravity — •Sukhjovan S Gill[1], Magdalena Misslisch[1], Baptist Piest[1], Ioannis Papadakis[2], Vladimir Schkolnik[2], Sheng-wey Chiow[3], Nan Yu[3], and Ernst M Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover, Germany 30167 — [2]Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany 12489 — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA 91109

The nature of Dark energy is one of the biggest quests of modern physics. It is needed to explain the accelerated expansion of the universe. In the chameleon theory, a hypothetical scalar field is proposed, which might affect small test masses like dilute atomic gases. In the vicinity of bulk masses, the chameleon field is hidden due to a screening effect making the model in concordance with observations. Dark Energy Search using Interferometry in the Einstein-Elevator(DESIRE) studies the chameleon field model for dark energy using Bose-Einstein Condensate of ^{87}Rb atoms as a source in a microgravity environment. Einstein-Elevator provides 4 seconds of microgravity time for multi-loop atom interferometry to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity. This method suppresses the influence of vibrations, gravity gradients and rotations via common mode rejection. The specially designed test mass suppresses gravitational effects from self-mass and its environment. This work will further constrain thin-shell models for dark energy by several orders of magnitude.

Q 59.9 Thu 16:30 Empore Lichthof

Experimental platform for multi-axis inertial quantum sensing — •Matthias Gersemann[1], Sven Abend[1], Mouine Abidi[1], Philipp Barbey[1], Mikhail Cheredinov[1], Ashwin Rajagopalan[1], Ann Sabu[1], Yueyang Zou[1], Christian Schubert[2], Ekim T. Hanimeli[3], Sven Herrmann[3], Simon Kanthak[4], Ernst M. Rasel[1], and the QUANTUS team[1,3,4,5,6,7] — [1]Institut für Quantenoptik, LU Hannover — [2]DLR-SI, Hannover — [3]ZARM, Uni Bremen — [4]Institut für Physik, HU zu Berlin — [5]Institut für Quantenphysik, Uni Ulm — [6]Institut für Angewandte Physik, TU Darmstadt — [7]Institut für Physik, JGU Mainz

In light pulse atom interferometry, ultracold atoms open the prospect of developing new techniques and concepts, in particular to increase the sensitivity of inertial measurements.

The possibility of precise motion control combined with large momentum transfer through double Bragg diffraction and Bloch oscillations contributed to the development of a new concept to create two simultaneous interferometers from a single BEC, as employed for the differentiation between rotations and accelerations. Thanks to the symmetry of this geometry, its extension can form the basis for a compact six-axis quantum inertial measurement unit based on atom-chip technology.

The underlying concepts, the system design used for this purpose, and the technical realization are presented in this contribution.

Q 59.10 Thu 16:30 Empore Lichthof

The Very Long Baseline Atom Interferometry facility for high precision gravity measurement — •Ali Lezeik[1], Mario Montero[1], Klaus Zipfel[1], Dorothee Tell[1], Vishu Gupta[1], Christian Meiners[1], Henning Albers[1], Sebastian Bode[1], Ernst Rasel[1], Christian Schubert[1,2], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover- Insititut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik

Matter-wave interferometry is a sequence of light pulses used to manipulate an ensemble of ultracold atoms and let them interfere. This interference pattern provides information about the intertial forces acting on the atoms, making atom interferometers useful devices for metrological applications and testing fundamental physics. As their sensitivity scales quadratically with the freefall time, a second-long free fall of the atoms allows to reach acceleration sensitivities of 1 nm/s^2, comparable to the best classical gravimeters. Excellent control over the environment and a high number of atoms in the ensemble is also necessary to reduce systematic effects and enhance the signal to noise ratio. The 15 m high Very Long Baseline Atom Interferometry facility (VLBAI) aims for sub nm/s^2 gravity measurement sensitivities.

We present the current status of the VLBAI and outline the distinguishing aspects of the facility that includes a dual source chamber of ytterbium and rubidium, a 10 m long UHV baseline magnetically shielded to below 1.5 nT/m, and a seismic attentuation system for intertial referencing.

Q 59.11 Thu 16:30 Empore Lichthof

Absolute light-shift compensated laser system for a twin-lattice atom interferometry — •Mikhail Cheredinov[1], Matthias Gersemann[1], Ekim T. Hanimeli[2], Simon Kanthak[3], Sven Abend[1], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU zu Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Twin-lattice atom interferometry is a method for forming symmetric interferometers with matter waves of large relative momentum by using two optical lattices propagating in opposite directions. A limiting factor is the loss of contrast associated with the AC Stark shift of far detuned light fields. This contribution presents the realization of a high power laser system for absolute light shift compensation and its potential for enhancing the interferometric contrast. The optical setup relies on two independent frequency doubling stages. One cavity produces the needed light fields for twin-lattice interferometry and another one produces one light field for AC Stark compensation.

Key features are the beam overlap on an interference filter with low power loss and coupling of high optical power in a photonic crystal fiber and further collimation of the output profile with flat-top beamshaper. The final beam contains the three linearly polarized light fields. Thanks to the flat-top shaped beam with more uniform intensity distribution it can be passed through our apertures with significantly less diffraction effects.

Q 59.12 Thu 16:30 Empore Lichthof

Multi-axis quantum gyroscope with multi-loop atomic Sagnac interferometry — •Ann Sabu[1], Yueyang Zou[1], Mouine Abidi[1], Philipp Barbey[1], Ashwin Rajagopalan[1], Christian Schubert[1,2], Matthias Gersemann[1], Dennis Schlippert[1], Ernst Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

Large area enclosed atom interferometers are potential devices for rotation measurements in inertial navigation. We aim at developing a compact and portable demonstrator capable of multi-axis inertial sensing, enabling precise measurement of rotations and accelerations. In future, an experimental realization of multi-loop atomic interferometry using such a portable gyrosope is also possible.

We present a brief theory of multi-loop atomic Sagnac interferometry, the current status of the preliminary system design of the demonstrator using the Bose-Einstein condensates (BECs) of ^{87}Rb atoms. We also present the design of the laser system for beamsplitter, cooling and detection sequence.

We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and through the CRC 1227 (DQ-mat), as well as support from DLR with funds provided by the BMWi under grant no. DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+).

Q 59.13 Thu 16:30 Empore Lichthof

A state-of-the-art suppression of seismic noise. The Seismic attenuation for Very Long Baseline Atom Interferometry — •Jonas Klussmeyer, Sebastian Bode, Klaus Zipfel, Christian Schubert, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The increased separation time of atomic ensembles in a Very Long Baseline Atom Interferometer (VLBAI) allows one to scale up the sensitivity to inertial effects. Likewise, however this also increase the sensitivity to seismic noise introduced by the retro reflection mirror, which acts as an inertial reference. This noise source limits State-of-the-art atom interferometers (AI).

Here we present the VLBAI Seismic Attenuation System (SAS), which combines passive seismic attenuation in all degrees of freedom via an inverted pendulum hanging on geometric anti-springs with a vertical resonance frequency of 320 mHz. In order to suppress residual motion at the resonance, we aim for an active feedback utilizing various inertial sensors and actuators. The estimated instability using the SAS as an inertial reference has been calculated to around $10^{-6}\,\frac{\mathrm{m}}{\mathrm{s}^2}$ per shot (drop: $2T = 0.8\,\mathrm{s}$, launch: $2T = 2.8\,\mathrm{s}$). Measuring the residual motion using an out-of-loop low-noise seismometer opens the path for either a direct feedback on the laser phase or a post-correction of the AI signal for reaching a $10^{-9}\,\frac{\mathrm{m}}{\mathrm{s}^2}$ per shot instability, close to the shot noise limit for our 10^6 atoms.

Q 59.14 Thu 16:30 Empore Lichthof

Moving towards high precision classical sensor hybridization with atom interferometers — •Ashwin Rajagopalan, Ernst Rasel, Sven Abend, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Vibrational noise is one amongst the most dominant noise sources that hinders the measurement sensitivity of an atom interferometer. Although correlation with commercial accelerometers can be a solution, there are limitations in terms of compatibility, dimensions, sensitivity and correlation efficiency with the atom interferometer. The perspective is to measure the inertial reference mirror motion with utmost precision, which in turn enhances the measurement sensitivity of the atom interferometer. For this purpose, the accelerometer should be placed as close as possible to the mirror or even better if fully integrated with it. We have already demonstrated using a compact Opto-mechanical resonator directly on the inertial reference mirror to measure its motion and suppress the effects of vibrational noise on a T = 10 ms atom interferometer without any vibration isolation. The next step is to fully integrate the Opto-mechanical motion sensor with the inertial reference mirror such that the same test mass serves as the inertial reference mirror as well as one of the mirrors for the optical interferometer measuring motion. This eradicates the existence of a mechanical transfer function between the mirror and the motion sensor. Funded by the DFG EXC2123 QuantumFrontiers - 390837967 supported by the DLR with funds provided by BMWK under Grant No. DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+).

Q 59.15 Thu 16:30 Empore Lichthof

Large-momentum-transfer atom interferometers with μrad-accuracy using Bragg diffraction — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], Christian Schubert[2,3], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik

Large-momentum-transfer atom interferometers that employ elastic Bragg scattering from light waves are among the most precise quantum sensors available. To increase their accuracy from the mrad to the μrad regime, it is necessary to understand the rich phenomenology of Bragg interferometers, which can be quite different from that of a standard two-mode interferometer. We develop an analytic model for the interferometer signal and demonstrate its accuracy using extensive numerical simulations. Our analytic treatment enables the determination of the atomic projection noise limit of an LMT Bragg interferometer and provides the means to saturate this limit. It allows suppression of systematic phase errors by two orders of magnitude down to a few μrad using appropriate pulse parameters.

This work is supported through the DFG via QuantumFrontiers (EXC 2123), and DQ-mat (CRC1227) within Projects No. A05, No. B07, and No. B09.

Q 59.16 Thu 16:30 Empore Lichthof

Noise Description in Bragg Atom Interferometer Using Squeezed States — •Julian Günther[1,2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Using entanglement for N-particle states in matter wave interferometers allows one to outperformthe standard quantum limit of $\frac{1}{\sqrt{N}}$ and approach the Heisenberg scaling of $\frac{1}{N}$ for the uncertainty inthe phase measurement $\Delta\phi$. We consider specifically the use of one-axis twisted, spin squeezed atomicstates in a Bragg Mach-Zehnder interferometer. We evaluate the phase uncertainty $\Delta\phi$ in the phasemeasurement taking into account the multi-port and multi-path nature of the Bragg Mach-Zehnderinterferometer, and determine optimally squeezed states for a given interferometer.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding origanisation DFG (project number 499225223).

Q 59.17 Thu 16:30 Empore Lichthof

Raman and Bragg diffractions in a combined system — •Ekim T. Hanimeli[1], Simon Kanthak[2,3], Matthias Gersemann[4], Mikhail Cheredinov[4], Sven Herrmann[1], Claus Lämmerzahl[1], Sven Abend[4], Ernst M. Rasel[4], and the QUANTUS team[1,2,3,4,5,6] — [1]ZARM, Universität Bremen — [2]Institut für Physik, HU Berlin — [3]Ferdinand-Braun-Institut, Berlin — [4]Institut für Quantenoptik, LU Hannover — [5]Universität Ulm — [6]Technische Universität Darmstadt

Combining Bragg and Raman processes allow for manipulation of both internal and external states of atoms in matter-wave interferometry. This enables novel interferometry topologies with the inclusion of techniques such as blow-away pulses, and clock interferometry. In order to investigate the possibilities arising from their combined use, we have realized a system capable of implementing both interrogation techniques, as well as single, double or higher order diffractions in a single setup. Here, we present some preliminary results from the implementation of this system for BEC interferometry.

The project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant number DLR 50WM2250C (QUANTUS+).

Q 59.18 Thu 16:30 Empore Lichthof

Momentum entanglement for atom interferometry — •Christophe Cassens[1], Fabian Anders[1], Alexander Idel[1], Polina Feldman[2], Dmitry Bondarenko[2], Sina Loriani[1], Karsten Lange[1], Jan Peise[1], Mathias Gersemann[1], Bernd Meyer-Hoppe[1], Sven Abend[1], Naceur Gaaloul[1], Christian Schubert[1,3], Dennis Schlippert[1], Luis Santos[2], Ernst Rasel[1], and Carsten Klempt[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Deutschland — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Deutschland — [3]Deutsches Zentrum fur Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, c/o Leibniz Universität Hannover, DLR-SI, 30167 Hannover

Compared to light interferometers, the flux in cold-atom interferometers is low and the shot noise large. Sensitivities beyond this limitation require the preparation of entangled atoms in different momentum modes.

Here entangled twin-Fock states are deterministically created in the internal spin-degree of freedom of a Bose-Einstein condensate. Hereupon, the entanglement is transferred to distinct momentum-modes using two-photon Raman transitions and verified by measurement of a squeezing parameter.

The observed mode quality and the residual expansion demonstrate that this entangled source is well-suited to the application in light-pulse atom interferometers and opens up a path towards gravimetry

beyond the standard quantum limit.

Q 59.19 Thu 16:30 Empore Lichthof

BECCAL - The Bose-Einstein Condensate and Cold Atom Laboratory — •Christian Deppner[1], Holger Ahlers[1], Patrick Brunssen[2], Marcel Eichelmann[1], Kai Frye-Arndt[1,3], Caroline Lösch[2], Arne Wacker[1], Meike List[2], Ernst M. Rasel[3], Waldemar Herr[1], Christian Schubert[1], and The BECCAL Team[1,2,3,4,5,6,7,8,9,10] — [1]DLR-SI, Callinstr. 30B 30167 Hannover, Germany — [2]DLR-SI, Am Fallturm 9, 28359 Bremen, Germany — [3]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [4]DLR-QT — [5]DLR-SC — [6]Inst. für Quantenphysik, UUlm — [7]Inst. für Physik, JGU — [8]Inst. für Physik, HUB — [9]ZARM, Bremen — [10]FBH, Berlin

The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is a NASA-DLR collaboration which will be a facility for conducting experiments with ultra-cold atoms and Bose-Einstein Condensates (BECs) aboard the International Space Station (ISS). BECCAL will enable the development of future quantum sensors based on matter-wave interferometry. The long term microgravity conditions on the ISS offer a unique environment for precision measurements as well as for fundamental research. We report on experimental opportunities and possible measurements with BECCAL. A detailed insight into the physics-package, where the ultra-cold atomic ensembles will be created and manipulated to perform these measurements will be given. Additionally, we show the microgravity and space heritage BECCAL is based on.

Q 59.20 Thu 16:30 Empore Lichthof

Utilizing Bose-Einstein condensates for atom interferometry in the transportable Quantum Gravimeter QG-1 — •Pablo Nuñez von Voigt[1], Nina Heine[1], Waldemar Herr[2], Christian Schubert[2], Ludger Timmen[3], Jürgen Müller[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik, Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The transportable Quantum Gravimeter QG-1 is designed to determine local gravity to the low nm/s^2 level of uncertainty. It relies on the interferometric interrogation of magnetically collimated Bose-Einstein condensates (BEC) in a transportable setup. An atom-chip plays a major role in creating the BEC, allowing high controllability of the atomic cloud. In connection with the absorption detection a better characterization of uncertainties of the motional degrees of freedom is possible. For our current setup, we also discuss methods for operating the gravimeter in seismically noisy environments.

We acknowledge financial funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 59.21 Thu 16:30 Empore Lichthof

A compact setup for optically guided BEC interferometry at a single wavelength — •Simon Kanthak[1,2], Ekim Hanimeli[3], Matthias Gersemann[4], Mikhail Cheredinov[4], Sven Abend[4], Ernst M. Rasel[4], Markus Krutzik[1,2], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Physik, HU Berlin — [2]Ferdinand--Braun-Institut, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Quantenoptik, LU Hannover — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Quantenphysik, Universität Ulm

Precision sensing with Bose-Einstein condensates (BECs) has been achieved in macroscopic free-space atom interferometers with underlying large scale enclosed space-time areas. As an alternative approach, trapped atom systems offer the opportunity for BEC sensors in more compact packages. For this purpose, atoms can be Bose condensed, delta-kick collimated, guided, split and recombined in optical potentials, which requires an optical guide, crossed beams and beam splitters usually at different wavelengths.

We report on our design and results with a linear setup for optically guided BEC interferometry at a single wavelength. Here, an atom chip serves to initially generate and delta-kick collimate a BEC inside a horizontally aligned atomic waveguide. A far-detuned focused beam in a retro-reflector configuration provides both tools to levitate and symmetrically split the wave packets via double Bragg diffraction.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Climate Action (BMWK) under Grant No. 50WM2250B (QUANTUS+).

Q 59.22 Thu 16:30 Empore Lichthof

Designing high precision electronics for atom interferometers in space applications — •Alexandros Papakonstantinou, Isabell Imwalle, Christian Reichelt, Matthias Koch, Thijs Wendrich, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

Atom interferometers are a powerful tool for precision measurements. Their sensitivity scales with the free fall time, which on ground is limited by the size of the vacuum chamber. In microgravity this limitation disappears, enabling higher sensitivities. However, typical microgravity platforms like sounding rockets or the ISS have restrictions on size, weight and power. Also, the apparatus needs to be robust enough to survive the trip into space. In addition it should be fully remote controlled with a high degree of automation. For our microgravity experiments QUANTUS-1/-2 (drop tower), MAIUS-1/-2 (sounding rocket) and BECCAL (ISS), we have developed such components, including laser current drivers, atom-chip current drivers, RF and microwave generators, photodiode and temperature monitoring, power supplies and many more. This poster will show the progress and latest results of our developments.

Q 59.23 Thu 16:30 Empore Lichthof

Atom interferometry in microgravity on long time scales — •Dorthe Leopoldt[1], Anurag Bhadane[2], Merle Cornelius[3], Laura Pätzold[3], Julia Pahl[4], Ernst Rasel[1], and Quantus Team[1,2,3,4,5,6] — [1]LU Hannover — [2]JGU Mainz — [3]U Bremen — [4]HU Berlin — [5]U Ulm — [6]TU Darmstadt

Atom interferometry allows for precise quantum sensors, which can e.g. be used to perform a quantum test of Einstein's equivalence principle. The QUANTUS-2 experiment enables rapid BEC production of Rb-87 with over 1e5 atoms and performs atom interferometry under extended free fall at the ZARM drop tower in Bremen. With that it serves as a testbed for future space-based missions. By applying a quadrupole mode enhanced magnetic lens, we are able to reduce the total kinetic energy of the BEC down to 3/2*k_B*38 pK in three dimensions in order to increase the ensemble's density. Here, we present the latest results on single species atom interferometry in QUANTUS-2 and our next steps, including the implementation of potassium.

The QUANTUS project is supported by the DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50WM1952-1957.

Q 59.24 Thu 16:30 Empore Lichthof

Matter-Wave optics with time-averaged potentials and tunable interactions — •Henning Albers[1], Alexander Herbst[1], Wei Liu[1], Dorothee Tell[1], Ernst M. Rasel[1], Dennis Schlippert[1], and The PRIMUS-Team[2] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]ZARM, Universität Bremen

The performance of matter-wave sensors highly depends on the center-of-mass motion and the expansion rate of the atomic ensemble. Time-averaged optical dipole traps give rise to nearly arbitrary dynamic potentials. Alongside with magnetic traps, such as those used in atom chip traps, they can provide fast Bose-Einstein condensate production. Here time-averaged potentials overcome the limitations of typical dipole traps by conserving the trap frequencies during evaporative cooling. The all-optical approach additionally allows to tune the atomic interactions by means of magnetic Feshbach resonances. We discuss our latest results of combining dynamic optical potentials with tunable interactions when performing evaporative cooling [1] as well as applying all-optical matter-wave lenses [2].

[1] A. Herbst et al., PRA (2022): Rapid generation of all-optical ^{39}K Bose-Einstein condensates using a low-field Feshbach resonance
[2] H. Albers et al., CommPhys (2022): All-optical matter-wave lens using time-averaged potentials

Q 59.25 Thu 16:30 Empore Lichthof

Effective theory for Bloch-oscillation-based LMT atom interferometry — •Florian Fitzek[1,2], Jan-Niclas Siemss[1,2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Light-pulse atom interferometers are quantum sensors that enable a wide range of high-precision measurements such as the determination of inertial and electromagnetic forces or the fine-structure constant. Increased sensitivities can be achieved by implementing large momentum transfer (LMT) techniques. A well-known method to increase the momentum of the arms of an interferometer are sequential Bloch oscillations.

We present an accurate description for Bloch pulses based on Wannier-Stark states [Glück et al., Physics Reports 366, 6 (2002)] and the adiabatic theorem for non-hermitian Hamiltonians and verify our model by comparing to an exact numerical integration of the Schrödinger equation [Fitzek et al., Sci Rep 10, 22120 (2020)]. Based on this model, we characterize losses as well as phase uncertainties induced by lattice depth fluctuations in the context of LMT atom interferometry.

This work is supported through the Deutsche Forschungsgemeinschaft (DFG) under EXC 2123 QuantumFrontiers, Project-ID 390837967 and under the CRC1227 within Project No. A05 as well as by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 59.26 Thu 16:30 Empore Lichthof

Quantum-clock interferometry — •Mario Montero[1], Ali Lezeik[1], Klaus Zipfel[1], Ernst M. Rasel[1], Christian Schubert[1,2], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover- Insititut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik

Universality of Gravitational Redshift (UGR) states that the time dilation measured by two objects in a gravitational field is independent of their composition. Testing the validity of UGR can be achieved through Quantum-Clock Interferometry (QCI), where a sequence of light pulses is used to split, redirected and recombined wave packets and drive transitions between internal states of the atom to measure a phase shift between the interferometer arms. However only certain space-time geometries are sensitive to gravitational time dilation effects [1].

We discuss proposals for QCI geometries that are sensitive to the gravitational redshift, and our approach for an experimental implementation in the Very Long Baseline Atom Interferometry (VLBAI) facility in Hannover [2]. Due to its long lived clock state, ytterbium (Yb) is an appealing candidate to measure differences in proper time. We present the current status of our high-flux source of laser-cooled Yb-174 atoms [3].

[1] C. Ufrecht et al, Phys. Rev. Research 2, 043240 (2020).
[2] D. Schlippert et al, arXiv:1909.08524 (2019).
[3] E. Wodey et al, J. Phys. B: At. Mol. Opt. Phys. 54 035301 (2021).

Q 59.27 Thu 16:30 Empore Lichthof

Principal Component Analysis for Image processing in Atom Interferometry — •Stefan Seckmeyer[1], Holger Ahlers[1,2], Sven Abend[1], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR) Institut für Satellitengeodäsie und Inertialsensorik,, Hannover, Germany

Image analysis plays an important role in several current state-of-the-art atom interferometry experiments. We investigate the extraction of physical quantities from absorption images of atom interferometers using principal component analysis (PCA).

As a starting point we take a simple mathematical model for the images of the output ports of a two-port atom interferometer which is using a Bose-Einstein condensate as an atom source.

We show an analytic prediction of the PCA results for a subset of parameters which allows us to ascribe physical quantities to the output of a PCA analysis. Using this method we are not only able to extract the interferometer phase for each image but also a spatial phase aberration map shared by all images, here introduced at the final beam splitter.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. 50WM2253A.

Q 59.28 Thu 16:30 Empore Lichthof

Towards a three axes quantum hybrid inertial sensor for mobile applications — •David Latorre Bastidas[1], Dennis Knoop[2], André Wenzlawski[1], Jens Grosse[2], Sven Herrmann[2], and Patrick Windpassinger[1] — [1]Institute of Physics, JGU Mainz — [2]ZARM, University of Bremen

Quantum hybrid inertial sensors based on cold atoms have been proposed as an accurate acceleration tracking alternative to current classical accelerometers. Such hybrid sensors allow a higher repetition rate and dynamic range than pure quantum atom interferometers. In this project, we plan to build a combination of an atom interferometer based on stimulated Raman transitions in a Mach-Zehnder configuration using Rubidium-87 with opto-mechanical sensors. For applications such as navigation or missions in space, optimization of the sensor in terms of size, weight and power are necessary, making it inevitable to find the optimal operating parameters.

This poster will give an overview of the current design and of the simulations that were used to optimize the measurement sequence. Further, an outlook is given on future on-site measurements and intermediate goals of the project.

Q 59.29 Thu 16:30 Empore Lichthof

Simulating space-borne atom interferometers for Earth Observation and tests of General Relativity — •Christian Struckmann[1], Ernst M. Rasel[1], Peter Wolf[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université 61 avenue de l'Observatoire, 75014 Paris, France

Quantum sensors based on the interference of matter waves provide an exceptional performance to test the postulates of General Relativity by comparing the free-fall acceleration of matter waves of different composition. Space-borne quantum tests of the universality of free fall (UFF) promise to exploit the full potential of these sensors due to long free-fall times, and to reach unprecedented sensitivity beyond current limits.

In this contribution, we present a simulator for satellite-based atom interferometry and demonstrate its functionality in designing the STE-QUEST mission scenario, a satellite test of the UFF with ultra-cold atoms to 10^-17 as proposed to the ESA Medium mission frame [https://arxiv.org/abs/2211.15412]. Moreover, we will highlight the possibility of this simulator to design Earth Observation missions going beyond state of the art such as the CARIOQA concept [https://arxiv.org/abs/2211.01215].

This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 59.30 Thu 16:30 Empore Lichthof

The Hannover Torsion Balance - a test platform for novel inertial sensing concepts — •Carolin Cordes, Christoph Gentemann, Gerald Bergmann, Moritz Mehmet, Gerhard Heinzel, and Karsten Danzmann — AEI Hannover

Gravity satellite missions require sensors that are sensitive to extremely small displacement changes of macroscopic test masses down to the millihertz regime. For the development of such novel sensors an environment is needed that resembles the conditions in space. Torsion pendulums can be used to simulate free-falling test masses in at least one degree of freedom in the lab on earth. For this reason, they are suitable testbeds for low frequency motion sensors. At the Albert Einstein Institute, we develop and construct such a test facility: the Hannover Torsion Balance, in which four dummy test masses are suspended as a torsion pendulum. A precise readout and control of the test mass motion is essential. To this end, an optical lever readout system and a capacitive readout and control system are implemented. A first interferometric readout will improve the test mass readout and control. To this aim, a Michelson interferometer will be added to the Torsion Balance. It will furthermore be an integral step towards testing novel optical satellite motion sensor readout techniques, such as Deep Frequency Modulation Interferometry. The poster will present the current status of the Torsion Balance and the latest results of the interferometric readout.

Q 59.31 Thu 16:30 Empore Lichthof

GRACE Follow-On and the Laser Ranging Interferometer: Measuring Earth Gravity from Space — •Malte Misfeldt[1,2], Vitali Müller[1,2], and Gerhard Heinel[1,2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover — [2]Max-Planck Institut für Gravitationsphysik

The GRACE (Gravity Recovery And Climate Experiment) Follow-On twin satellites were launched in mid 2018 for continuity of the Earth gravity field measurements from GRACE (2002-2017). Formerly, the ranging measurement was performed using microwave interference. However, GRACE-FO hosts the novel Laser Ranging Interferometer

(LRI), a technology-demonstrator for proving the feasibility of laser interferometry for precise inter-satellite ranging. The LRI surpasses the accuracy of the conventional microwave by a factor of 500 at high frequencies, which possibly enables new analysis techniques and insights into hydrological processes on Earth's surface.

This presentation discusses the design and working principle of the LRI are discussed. Furthermore, an outlook toward the next generation of gravity missions with an improved version of the LRI as the primary ranging instrument is given.

Q 59.32 Thu 16:30 Empore Lichthof

Balanced homodyne detection design and application at the AEI 10m Prototype facility — •Matteo Carlassara[1,2], Firoz Khan[1,2], Philip Koch[1,2], Johannes Lehmann[1,2], Harald Lück[1,2], Juliane von Wrangel[1,2], Janis Wöhler[1,2], and David S. Wu[1,2] — [1]Leibniz Universität Hannover, Hannover, DE — [2]Max Planck Institute for Gravitational Physics, Hannover, DE

Fundamental sources of quantum noise currently limit the performance of ground-based interferometric gravitational wave detectors (GWD), but ongoing technical improvements offer opportunities pushing past this limit. To further upgrade GWD sensitivity, as in the planned Einstein Telescope and Cosmic Explorer, the interferometer readout is planned to be a Balanced Homodyne Detection scheme (BHD) with suspended components to allow the interferometer to operate at a true dark fringe. This also allows the interferometer to be read out at arbitrary quadratures, which will be required by some advanced techniques to suppress quantum noise. The implementation of BHD involves overcoming a number of technical difficulties, including the creation of a very stable local oscillator (LO) and its active stabilisation. This poster focuses on an overview of the relevant issues and obstacles to implementing a BHD using the Albert Einstein Institute (AEI) 10m Prototype, an optimal facility to study novel technologies for reaching and surpassing the interferometric standard quantum limit (SQL). A report will be made on the current progress in the application of BHD with the construction of one of the triple mirror suspensions required for the LO's path.

Q 59.33 Thu 16:30 Empore Lichthof

Compact Optical Test Mass Sensing — •Victor Huarcaya — Albert-Einstein-Institut Hannover / Max-Planck-Institut für Gravitationsphysik, Hannover, Germany

High-precision measurement of all six degrees of freedom of freely floating test masses is necessary for gravitational space missions like GRACE (Gravity Recovery and Climate Experiment), its follow-on mission GRACE-FO, and GOCE (Gravity Field and steady-state Ocean Circulation Explorer). When aiming for sensing multiple degrees of freedom, typically, capacitive sensing is used, which facilitates a compact setup but does not provide competitive precision. In opposition, laser interferometers have been established as one of the tools of choice for high-precision measurement schemes. However, these measurements were restricted to the length changes in one degree of freedom. Here, we report on Deep Frequency Modulation (DFM). This novel interferometric readout technique is a promising candidate for improving the sensitivity beyond capacitance readout systems and reducing the complexity of the setup. Initial experimental results show optical zero measurements performance levels better than $250\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$ at 1 mHz and electronic readout noise levels below $1\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$ at 1 mHz. Based on DFM, we also report a novel sensor topology, the self-referenced single-element dual-interferometer (SEDI) inertial sensor, which takes simplification one step further by accommodating two interferometers in one optic which makes the SEDI sensor a promising approach for applications in high precision inertial sensing for both next-generation space-based gravity missions.

Q 59.34 Thu 16:30 Empore Lichthof

Scaling a robust Lorentz Symmetry test to multiple Yb$^+$ ions — •Kai C. Grensemann[1], Chih-Han Yeh[1], Laura S. Dreissen[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We recently completed a test of local Lorentz invariance (LLI) in the electron-photon sector using a single trapped ^{172}Yb$^+$ ion [1]. With a novel approach based on composite pulse Ramsey spectroscopy [2] we fully exploited the ion's high sensitivity to Lorentz violation (LV) [3] and reached second long coherence times. We extracted improved bounds on LV coefficients in the 10^{-21} region. Scaling the used method to a linear Coulomb crystal of N ions would further increase the sensitivity by $\sqrt{N}$. Here, we report on our ongoing efforts to test LLI on a 10 ion crystal. We show that the composite pulse sequence is highly robust against inhomogeneities of the magnetic and interaction fields, enabling easy upscaling to a 100 μm ion crystal. We also report on the progress of coherent multi-ion octupole excitation for efficient population of the F-state. The AC-Stark shift of several 100 Hz compared to a linewidth of 10 Hz [4] demands intensity deviations below $\pm 4\%$, which we achieve by shaping the beam with a holographic phaseplate.

[1] L.S. Dreissen et al., *Nat. Commun.* **13**, 7314 (2022). [2] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018). [3] V.A. Dzuba et al., *Nature Physics* **12**, 465-468 (2016). [4] H. A. Fürst et al., *Phys. Rev. Lett.* **125**, 163001 (2020).

Q 59.35 Thu 16:30 Empore Lichthof

Progress on PTB's transportable Al$^+$ ion clock — •Constantin Nauk[1], Benjamin Kraus[1,2], Joost Hinrichs[1,3], Simone Callegari[1], Stephan Hannig[1,2], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks achieve fractional systematic and statistical frequency uncertainties on the order of 10^{-18}. This enables novel applications, such as height measurements in relativistic geodesy with ~ 1 cm resolution for earth monitoring. Towards this goal, we set up a transportable clock based on the $^1\mathrm{S}_0 \to {}^3\mathrm{P}_0$ transition in ^{27}Al$^+$. A co-trapped ^{40}Ca$^+$ ion allows state detection and cooling via quantum logic spectroscopy and sympathetic cooling.

We present the design and the current status of the transportable apparatus, review the recent development of the laser systems and show particularly the performance of the UV clock laser setup operating at 267.4 nm with a fractional frequency uncertainty of 10^{-16} at 1 second.

Q 59.36 Thu 16:30 Empore Lichthof

Compact rack-integrated UV laser system for a transportable Al$^+$ quantum logic optical clock — •Joost Hinrichs[1,2], Stephan Hannig[1,3], Benjamin Kraus[1,3], Constantin Nauk[1], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany — [3]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany

Optical atomic clocks currently provide the most precise frequency standards. For side-by-side comparisons or applications in relativistic geodesy, transportable and robust setups with lowest possible uncertainties are necessary. The feature of transportability requires a highly-stable, compact and automatized implementation.

For our transportable ^{27}Al$^+$ clock all components, including optics and the vacuum chamber, will be integrated into conventional 19 in-racks. As one part of the clock apparatus we present a compact design of the Al$^+$ logic laser emitting at 267 nm to drive the $^1S_0 \leftrightarrow {}^3P_1$ transition. The system consists of a fibre laser operating at 1068 nm and two frequency doubling cavities to generate the required UV output for the logic transition. The complete optical setup is housed in one rack-integrated aluminium drawer. We present the setup and characterize its efficiency and long-term stability.

Q 59.37 Thu 16:30 Empore Lichthof

Variational Clock Protocols — •Timm Kielinski — Institute for theoretical physics, Hannover, Germany

Enhancement of clock stability beyond the classical limit can be accomplished by introducing entanglement between the atoms. In particular, one-axis-twisting (OAT) interactions receive much attention since they give enhanced sensitivity by generating squeezed spin states or echo protocols and can be reliably implemented in several experimental setups. In local (frequentist) phase estimation, the sensitivity is characterized using tools as the Fisher information and is limited by the Cramér Rao bound. However, laser noise limits the clock stability and therefore frequency fluctuations during the clock operation have to be considered. To accomplish for the finite prior information, Bayesian phase estimation is applied representing the trade-off between reduction in quantum projection noise (QPN) and the coherence time limit (CTL) of the laser. This work aims to optimize the stability of ion clocks building on a variational class of Ramsey protocols. Theoretical predictions are validated by numerical simulations of the full feedback loop of an atomic clock. The main limitation is imposed by fringe hops, especially in the presence of dead time.

Q 59.38 Thu 16:30 Empore Lichthof

A compact strontium optical clock based on Ramsey-Bordé spectroscopy — •Oliver Fartmann[1], Ingmari C. Tietje[1], Amir Mahdian[1], Marc Christ[1,2], Conrad L. Zimmermann[2], Martin Jutisz[1], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Inst. f. Physik — [2]Ferdinand-Braun-Institut GmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We present the status of our optical clock based on Ramsey-Bordé spectroscopy using the $^1S_0 \rightarrow {}^3P_1$ intercombination line at 689 nm in strontium. We give an overview of the underlying spectroscopy principle and a clock instability and uncertainty budget. Further, we present the current status in the laboratory including the design of a new compact and high-flux atomic oven and our work on the spectroscopy setup. Lastly, we show our progress towards micro-integrating the setup.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Climate Action (BMWK) under grant number DLR50WM1852 and by the German Federal Ministry of Education and Research within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 59.39 Thu 16:30 Empore Lichthof

Development of Two Laboratory Two-Photon Frequency References — •Moritz Eisebitt[1,2], Julien Kluge[1,3], Daniel Emanuel Kohl[1,3], Klaus Döringshoff[1,3], and Markus Krutzik[1,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]II. Physikalisches Institut, RWTH Aachen University — [3]Ferdinand-Braun-Insitut, Leibniz-Institut für Höchstfrequenztechnik

We present two laboratory monochromatic two-photon frequency references operating on the $5S_{1/2} \rightarrow 5D_{5/2}$ transition in Rubidium utilising frequency modulation spectroscopy. Two-photon references with Rubidium have the benefit of a narrow linewidth and being inherently Doppler-free. The references have a combined fractional instability below $3{\cdot}10^{-13}/\sqrt{\tau}$ up to 1000s. Efforts to stabilise the residual amplitude modulation are discussed as well as the performance and limits of the frequency reference induced by environmental effects. Measurements of the dipole, quadrupole and octupole hyperfine structure constants of Rb $5D_{5/2}$ are presented which surpass the precision of the current state of art values by an order of magnitude.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK19711, 50WM2164.

Q 59.40 Thu 16:30 Empore Lichthof

Recent Progress of a miniaturized all diode laser based strontium lattice clock — •Max Schlösinger[1], Henri Zimmermann[1], Christoph Pyrlik[1], Vladimir Schkolnik[1], Ronald Holzwarth[2], Robert Jördens[3], Enrico Vogt[4], Andreas Wicht[5], and Markus Krutzik[1,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin — [2]Menlo Systems GmbH, Bunsenstr. 5, 82152 Martinsried — [3]QUARTIQ GmbH, Rudower Chaussee 29, 12489 Berlin — [4]Qubig GmbH, Balanstr. 57, 81541 München — [5]Ferdinand Braun Institut GmbH, Gustav-Kirchhoffstraße 4, 12489 Berlin

The joint SOLIS-1G project aims to develop a size weight and power (SWaP) optimized, all diode-laser based strontium lattice clock demonstrator, thereby exploring and enabling essential technologies for future space-borne optical lattice clocks.

We report on the current state of the SOLIS-1G subsystems with a focus on the physics package, micro-integrated laser systems and compact control electronics.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WM2151 and DLR50RP2190B.

Q 59.41 Thu 16:30 Empore Lichthof

A multi-ion indium clock — •Ingrid M. Dippel[1], Moritz von Boehn[1], H. Nimrod Hausser[1], Jonas Keller[1], Jan Kiethe[1], Tabea Nordmann[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

Currently, single-ion optical clocks represent some of the most accurate experiments and are used in high-precision spectroscopy, metrology and geodesy [1]. Though very precise, the statistical uncertainty of these optical clocks is fundamentally limited by the low signal-to-noise ratios and require averaging times on the order of days to resolve frequencies at the limit of their systematic uncertainties at the 10^{-18} level. This motivates the approach to develop multi-ion systems, leading to reduced quantum projection noise (QPN) by a factor of $1/\sqrt{N_{\text{ion}}}$, which is limiting the statistical uncertainty of a clock. Thereby, the averaging times can be decreased by factor of N_{ion} for a given level of statistical uncertainty.

We present an experimental set-up based on $^{115}\text{In}^+$ ions sympathetically cooled by $^{172}\text{Yb}^+$ ions, aiming for multi-ion operation and at the same reaching frequency unertainties on the level of 10^{-19} [2]. Furthermore, we discuss future plans and methods for improving robustness, reducing systematic uncertainties and extending automation of basic lab routines and measurement processes.

[1] T. E. Mehlstäubler et al., *Rep. Prog. Phys.* **81**, 064401 (2018)
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019)

Q 59.42 Thu 16:30 Empore Lichthof

Development of a Miniaturized Two-photon Frequency Reference Towards Application on a Small Satellite Mission — •Daniel Emanuel Kohl[1,2], Julien Kluge[1,2], Moritz Eisebitt[2,3], Klaus Döringshoff[1,2], Sten Wenzel[2], Andrea Knigge[2], Andreas Wicht[2], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik, Humboldt-Universität zu Berlin — [3]II. Physikalisches Institut, RWTH Aachen University

Global navigation satellite systems require precise clocks with stringent constraints on size, weight and power budget. Two-photon spectroscopy of the rubidium 5S-5D transition in conjunction with optical frequency combs can provide compact, high precision clocks for next generation GNSS systems. We present a two-photon rubidium frequency reference set-up, achieving fractional frequency instabilities in the regime of $10^{-13}/\sqrt{\tau}$.

Furthermore, we present a prototype of a compact set-up, featuring a monolithically integrated extended cavity diode laser and a miniaturized, heated and magnetically shielded 1 cm long vapor cell. Details of the vapor cell assembly and the lasers system will be shown. This work, in combination with advanced micro-integration techniques, may lead to ultra-compact, low power but high performant optical frequency references.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RK1971, 50WM2164.

Q 59.43 Thu 16:30 Empore Lichthof

A strontium lattice clock with 3×10^{-18} uncertainty — •Kilian Stahl, Joshua Klose, Roman Schwarz, Ingo Nosske, Uwe Sterr, Sören Dörscher, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We present a strontium optical lattice clock, PTB-Sr3, that is equipped with in-vacuum heat shields providing a highly homogeneous thermal environment. Initial characterisation of systematic effects yields a fractional frequency uncertainty of about 3×10^{-18}. The clock has similar frequency instability as its predecessor, *i.e.*, below $2\times10^{-16}/\sqrt{\tau/\text{s}}$, and improved availability due to automated monitoring and recovery of laser frequency locks. We also report on a revisiting analysis of the atomic response to blackbody radiation (BBR), which reveals a previously unrecognised error in the dynamic correction coefficient corresponding to a 4×10^{-18} clock offset and improves the uncertainty of the atomic response near room temperature to about 1×10^{-18}. To improve the uncertainty of the BBR-induced frequency shift further, a closed-cycle cryocooler allows reducing the temperature of the heat shields to below 80 K. We discuss the prospects for improving the fractional frequency uncertainty of this clock into the 10^{-19} regime.

This project has been supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2123 QuantumFrontiers – Project-ID 390837967, SFB 1464 TerraQ – Project-ID 434617780 – within project A04, and SFB 1227 DQ-*mat* – Project-ID 274200144 – within project B02.

Q 59.44 Thu 16:30 Empore Lichthof

Towards a continuous wave superradiant Calcium Laser —

•David Nak and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, Hamburg, Deutschland

Superradiant Lasers are suitable as narrow light sources with ultralow bandwidth, as their emission frequency is only weakly dependent on an eigenfrequency of the laser cavity. They can be used as a read-out tool for precise optical atomic clocks. Currently, our experiment loads cold Calcium-40 atoms from a magneto optical trap into a one-dimensional optical lattice prepared inside a cavity. By incoherent population of the metastable triplet state, pulsed superradiant emission on the intercombination line was realized [1].

At present, the setup is being extended by an incoherent repumping mechanism, which will allow continuous wave operation.

[1] T. Laske, H. Winter, and A. Hemmerich, Pulse Delay Time Statistics in a Superradiant Laser with Calcium Atoms, Phys. Rev. Lett. 123, 103601 (2019).

Q 59.45 Thu 16:30 Empore Lichthof

Improving frequency superresolution with a resonant quantum pulse gate — •Dana Echeverría-Oviedo, Michael Stefszky, Jano Gil-López, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS).

The application of temporal mode selective measurements for time-frequency quantum metrology has been shown to reach the ultimate precision limit imposed by quantum mechanics and therefore saturate the quantum Cramér-Rao lower bound. These measurements can be implemented with a quantum pulse gate (QPG), a dispersion engineered device based on sum frequency generation between shaped pulses. In practice, the QPG finite phasematching (PM) bandwidth (BW) limits the achievable resolution of such measurements. Increasing the QPG length reduces its PM BW. However, building longer QPGs is not a trivial task since nonlinear crystals cannot be arbitrarily long and longer samples are more sensitive to fabrication imperfections degrading its PM spectrum. To alleviate this limitation, it is of paramount importance to tailor narrower PM BW, pushing the QPG to its performance limit. We propose a resonant QPG, which is composed of two coupled waveguide cavities. One of them is a nonlinear cavity in which the interaction occurs, while the other acts as a coherent filter to obtain a single resonance mode. Our design reduces the PM BW by 3 orders of magnitude for the same nonlinear interaction length of the corresponding QPG, yielding a 5.9 better resolution in superresolved metrology measurements.

Q 59.46 Thu 16:30 Empore Lichthof

The role of frequency stability in measurements of the coefficient of thermal expansion — •Nina Meyer, Tobias Ohlendorf, Uwe Sterr, and Thomas Legero — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

Materials with small coefficients of thermal expansions (CTEs) of about $10^{-8}\,K^{-1}$ at room temperature are needed for extreme-ultraviolet lithography, in space and ground-based telescopes or ultra-stable resonators. Those small CTEs are usually accurately measured by two-beam Michelson interferometers [1] or by multiple-beam interference based on Fabry-Pérot resonators [2].
Our approach is based on a Fabry-Pérot resonator, consisting of the test material as spacer and two mirrors in a temperature-controlled vacuum chamber. To measure the small thermal expansion, we stabilize a transfer laser onto the TEM_{00} mode of the optical resonator and observe the beat frequency of the transfer laser and a frequency standard.
In this poster, we compare the stability of different types of transfer lasers to iodine-stabilized lasers and ultra-stable lasers via a frequency comb and discuss its influence on the CTE accuracy. We also provide an outlook to setups with lasers operating at $1.5\,\mu$m wavelength.

[1] R. Schödel, Meas. Sci. Technol. **19**, 084003 (2008).
[2] F. Riehle, Meas. Sci. Technol. **9**, 1042−1048 (1998).

Q 59.47 Thu 16:30 Empore Lichthof

En Route to hour long spin manipulation established via constantly driven Rabi nutation measurements — •Tianhao Liu, Jens Voigt, Silvia Knappe-Grüneberg, and Wolfgang Kilian — Physikalisch-Technische Bundesanstalt, 10587 Berlin, Germany

We describe a method for estimating the Larmor frequency of polarized nuclear spins by utilising Rabi nutation that is driven by an applied near-resonant magnetic field. Two data analysis methods for retrieving the Larmor frequency from the precession signals recorded by magnetometers on top of the cell are proposed and further verified with numerical simulations. Compared to the commonly used free decay method, the proposed method has distinct advantages on smaller polarisation loss and shorter measurement time. Main systematic sources on the estimated Lamour frequency by this method are identified and quantitively analysed with a forward analytic model. A series of experiments, where a cell of 3He polarised via spin-exchange optical pumping is placed under a SQUID system in a magnetically shielded room, have been performed to validate this method. A preliminary analysis shows that the relative uncertainty of less than 10-6 on the Lamour frequency could be achieved with data taken within few hundred seconds. This method could be used for traceable weak magnetic field measurements. Moreover, it provides a basis for coherently manipulating the nuclear spins for over an hour-long interval. To the end, we will present a slow Rabi nutation of 3He driven by near-resonance magnetic field over 1 hour.

Q 59.48 Thu 16:30 Empore Lichthof

Testing novel high-reflectivity mirror coatings from room temperature to 4 K — •Mona Kempkes, Jialiang Yu, Sofia Herbers, Thomas Legero, Uwe Sterr, and Daniele Nicolodi — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Brownian thermal noise of highly reflective mirror coatings is the fundamental limit to the performance of many precision laser experiments. Very high reflectivity mirrors with significantly lower mechanical losses than traditional Ta_2O_5/SiO_2 multilayers are needed to improve the stability of optical resonators. Few promising alternatives have been developed so far. However, direct coating noise measurements in representative setups are required to validate their performance, as demonstrated by our experiments with $Al_{0.92}Ga_{0.08}As/GaAs$ crystalline coatings [J. Yu et al., arXiv:2210.15671 (2022) and D. Kedar et al., arXiv:2210.14881 (2022)]. We will present our setup for the characterization of mirror coatings performance and direct Brownian thermal noise measurements from room-temperature to 4 K in a cryogenic optical resonator. This facility will be used to test novel mirror solutions as meta-mirrors and amorphous-Si based coatings.

We acknowledge support by the Project 20FUN08 NEXTLASERS, which has received funding from the EMPIR programme cofinanced by the Participating States and from the European Union's Horizon 2020 Research and Innovation Programme and by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC-2123 QuantumFrontiers, Project-ID 390837967.

Q 59.49 Thu 16:30 Empore Lichthof

Vacuum-integration of a double-tip fiber microscope — •Florian Giefer, Lukas Tenbrake, Sebastian Hofferberth, and Hannes Pfeifer — Institute of Applied Physics, University of Bonn, Germany

Multi-mode cavity optomechanical systems are a promising platform for investigating many body dynamics, for distributed sensing, and optomechanical circuits. A prominent implementation of optomechanical experiments is the membrane-in-the-middle setup, where a thin suspended film is placed inside of an optical fiber Fabry-Perot cavity. To extend this platform towards multiple mechanical resonators with tailored properties we envisage employing 3D direct laser written membrane structures that are placed on a DBR substrate and interfaced using multiple fiber-tip integrated mirrors. To reduce mechanical dampening by surrounding air, our structures need to be placed in a vacuum environment. Based on the concept of "scanning cavity microscopes" introduced by Mader et al., we develop an experimental setup capable of interfacing optomechanical structures on DBR substrates in vacuum using two fiber mirrors with complete position control. We present the design, implementation challenges and future prospects of our experimental setup.

Q 59.50 Thu 16:30 Empore Lichthof

Programmable trap array of optically levitated nanoparticles — •Livia Egyed[1], Manuel Reisenbauer[1], Iurie Coroli[1], Murad Abuzarli[1], Uroš Delić[1], and Markus Aspelmeyer[1,2] — [1]University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), Boltzmanngasse 5, A-1090 Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria

Arrays of coupled mechanical oscillators have been proposed for studies of collective effects such as non-reciprocal phonon transport, investigation of topological phases or multipartite entanglement. Existing experimental architectures are usually either based on fabricated structures or use an optical cavity to mediate the interaction between multiple mechanical modes, thereby limiting the maximal number of elements and the versatility of the created interaction, as well as prohibiting individual detection of the oscillators.

Here, we present a novel platform for studying collective dynamics based on a tunable trap array of levitated nanoparticles which allows for independent control and readout of the particles motions. In addition to standard cavity-mediated setups, we exploit the light-induced dipole-dipole interactions between the particles to introduce direct coupling between them. The ability to control non-reciprocal particle interaction paves the way towards exploring many particle phenomena with massive objects. We will present this platform as well as first results on the collective dynamics of two interacting particles.

Q 59.51 Thu 16:30 Empore Lichthof

Optimal Control of Quantum Squeezed States — •Anton Halaski, Matthias G. Krauss, Daniel Basilewitsch, and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

Squeezed states are interesting for various tasks, including applications in quantum sensing or quantum information processing. We demonstrate how a mechanical resonator in an optomechanical setup can be brought into a squeezed state using optimal control theory. Using Krotov's method [Reich et al. *J. Chem. Phys.* **136**, 104103 (2012)], we show how optimal control theory can reduce the time needed for squeezed state generation by several orders of magnitude compared to protocols with constant driving. Further, we derive a general protocol for acquiring squeezed states, which not only allows us to simplify the general pulse shapes but also to understand the physical processes during the time evolution of the system.

Q 59.52 Thu 16:30 Empore Lichthof

Quantum state tomography of a nanomechanical resonator in a pulsed measurement protocol — •Felix Klein[1], Jakob Butlewski[1], Alexander Schwarz[2], Klaus Sengstock[1], Roland Wiesendanger[2], and Christoph Becker[1] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

Pulsed optomechanical experiments have received growing interest in recent years as they promise a convenient path to full state tomography of quantum objects. Instantaneous snapshots and squeezing of one motional quadrature project the measurement induced noise into the perpendicular quadrature enabling quantum limited high precision measurements.

We realize high fidelity quantum state tomography of a nanomechanical SiN trampoline resonator in a fiber fabry pérot cavity achieving a position uncertainty of 2 pm using light pulses much shorter than the resonators oscillation period.

Here we give an overview of the current experimental setup and discuss ongoing modifications that will allow resolving the resonators zero-point motion.

Q 59.53 Thu 16:30 Empore Lichthof

Levitated nanoparticles in microgravity — •Govindarajan Prakash, Vincent Hock, Marian Woltmann, Sven Hermann, Claus Lämmerzahl, and Christian Vogt — University of Bremen, ZARM (Centre for Applied Space Technology and Microgravity)

Optomechanical levitation of nanoparticles provides a promising platform to perform tests with macroscopic particles on the interface between quantum and classical regimes. Schemes of such tests involve optical trapping, feedback cooling, and release and retrapping of nanoparticles. Here, we aim to discuss how this allows us to perform force sensing of the order of attonewtons in microgravity conditions at the drop towers of ZARM in Bremen using silica nanoparticles. We present the progress thus far in our preliminary aim of building a force sensor that might be suitable for usage in space-based environments for dark matter searches and the like

Q 59.54 Thu 16:30 Empore Lichthof

Nonlinear Oscillator with a Single Trapped Ion — •Moritz Göb, Bo Deng, Max Masuhr, Kilian Singer, and Daqing Wang — Experimentalphysik I, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel

Nonlinear oscillators are interesting test systems for realizing thermal machines in the quantum regime. In our experiment, we investigate a single, laser-cooled $^{40}Ca^+$ ion confined in a funnel-shaped Paul trap. This trap geometry leads to an interaction of the axial and radial phonons, which resembles the optomechanical interaction described by the radiation pressure Hamiltonian. Based on this system, we measure and characterize this nonlinear interaction and the resulted mechanical bistability. In this poster, I will detail the technical implementation of this experiment.

Q 59.55 Thu 16:30 Empore Lichthof

Ultrastrong coupling in levitated optomechanics — •Iurie Coroli[1], Kahan Dare[1,2], Jannek Hansen[1], Aisling Johnson[1], Markus Aspelmeyer[1,2], and Uros Delic[1] — [1]University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), Boltzmanngasse 5, A-1090 Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Austrian Academy of Sciences, A-1090 Vienna, Austria

Levitated nanoparticles have long been heralded as an excellent platform for quantum sensing. Recent proposals have sought to utilize instability due to ultra-strong coupling via coherent scattering but this regime has been out of reach to experimental systems. We report the first levitated optomechanical system to operate in the ultrastrong coupling regime, reaching a maximum coupling of $gx/\Omega x = 0.5$ operating in the resolved sideband regime. We demonstrate future extensions to this system which can dramatically improve the optomechanical cooperativity and further boost the coupling rates, which opens up quantum experiments in the ultrastrong coupling or even deep strong coupling regime to simple table-top systems.

Q 59.56 Thu 16:30 Empore Lichthof

Studying exceptional points in an optical fiber — •Quentin Levoy[1], Flore K. Kunst[1], and Birgit Stiller[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität, Erlangen, Germany

Exceptional points (EPs) are physical features appearing in non-Hermitian systems, which are typically systems subjected to loss and gains. At these EPs, the eigenvectors of the system coalesce and unique physical phenomena are displayed, such as an unusual dispersion and higher sensitivity to perturbations. EPs are the object of both theoretical and experimental studies. Even though they are associated to ubiquitious properties such as gain and loss and open system behaviour, it is not always straightforward to identify a physical platform that provides the right parameters to reach these EPs and to experimentally study them. Recently, it was proposed to use nonlinear optics and more specifically optoacoustics to finely tune gain and loss in an experimental setup, for instance an optical fiber. Here, we explore in detail how the interaction of optical and acoustic waves can provide an interesting framework to explore the properties of EPs and non-Hermitian physics. Observing this interaction in an optical fiber is one possible way to experimentally observe and study EPs of different orders, using only an optical fiber and a few laser beams.

Q 59.57 Thu 16:30 Empore Lichthof

A nanofabricated solid immersion lens for bright and high-purity single-photon emission from a germanium-vacancy center in diamond — •Justus Christinck[1,2], Franziska Hirt[1,2], Helmuth Hofer[1], Markus Etzkorn[2,3], Zhe Liu[2,3], Toni Dunatov[4], Milko Jakšić[4], Jacopo Forneris[5,6,7], and Stefan Kück[1,2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology (LENA), Braunschweig, Germany — [3]Technische Universität Braunschweig, Braunschweig, Germany — [4]Ruder Bošković Institute, Zagreb, Croatia — [5]University of Torino, Torino, Italy — [6]Istituto Nazionale di Fisica Nucleare (INFN), Torino, Italy — [7]Istituto Nazionale di Ricerca Metrologica (INRiM)

The group IV-vacancy color centers in diamond, such as the germanium-vacancy (GeV) center, are potential candidates for quantum metrology applications at room temperature. We report on the fabrication of a GeV center doped diamond sample by implantation of Ge-ions and subsequent high-temperature vacuum annealing. To enhance the photon-extraction from the diamond, solid immersion lenses were fabricated into the diamond surface in a focused ion beam scanning electron microscope (FIB-SEM) setup. A bright GeV center in a solid-immersion lens was examined in terms of its saturation behavior and its single-photon purity through the measurement of the $g^{(2)}(\tau)$ function. A saturation count rate at the detector of

(833 ± 9) kcps was reached. A simultaneous count rate of 580 kcps and $g^{(2)}(0) = (0.12 \pm 0.06)$ were measured in the experiment.

Q 59.58 Thu 16:30 Empore Lichthof

Mechanically Isolated Quantum Emitters in Hexagonal Boron Nitride — •Andreas Tangemann[1], Patrick Maier[1], Michael Hoese[1], Prithvi Reddy[2], Andreas Dietrich[1], Michael K. Koch[1], Konstantin G. Fehler[1], Marcus W. Doherty[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany. — [2]Laser Physics Centre, Research School of Physics and Engineering, Australian National University, Australian Capital Territory 2601, Australia.

Single Photon emitters are a crucial resource for novel photonic quantum technologies. Quantum emitters hosted in two-dimensional hexagonal Boron Nitride (hBN) are a promising candidate for the integration into hybrid quantum systems. One type of emitters hosted in hBN has shown the remarkable property of Fourier limited linewidths from cryogenic up to room temperatures. This property can be attributed to mechanically isolated orbitals of the defect centers, which do not couple to in-plane phonon modes. Here, we present our recent results towards identifying the origin of this mechanical decoupling, which could be caused by out-of-plane emitters. We also present quantum random number generation using the symmetric dipole emission profile of these emitters.

Q 59.59 Thu 16:30 Empore Lichthof

Insights into the photophysics of the SnV center in diamond — •Philipp Fuchs[1], Johannes Görlitz[1], Michael Kieschnick[2], Jan Meijer[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken, Germany — [2]Universität Leipzig, Angewandte Quantensysteme, Linnéstraße 5, 04103 Leipzig, Germany

The negatively charged tin vacancy center (SnV^-) in diamond has been shown to be a versatile system that can be used as a quantum sensor, long-lived qubit, and single photon source. However, exploiting these properties requires active stabilization of the charge state, as the SnV^- can be easily ionized to its double negative charge state (SnV^{2-}) upon laser illumination, which is optically inactive [1].

In this work, we propose a simple rate equation model that includes this ionization process. We apply the model to an extensive set of measurements on different SnV centers, along with a thorough characterization of the efficiency of our measurement setup. We conclude that a charge-stabilized SnV^- center is a nearly ideal single photon source in terms of quantum efficiency, since we can describe any reduced photon rate by ionization to the optically inactive SnV^{2-} charge state without assuming other non-radiative decay channels.

[1] J. Görlitz et al., npj Quantum Inf 8, 45 (2022)

Q 59.60 Thu 16:30 Empore Lichthof

Optical investigations of evaporated dibenzoterrylene layers in a C60-fullerene matrix — •Franziska Hirt[1,2], Justus Christinck[1,2], Helmuth Hofer[2], Gunilla Harm[2,3], Andreas Reutter[2,3], Mike Stummvoll[2,3], Neda Noei[3], Uta Schlickum[2,3], and Stefan Kück[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]Laboratory for Emerging Nanometrology, Langer Kamp 6a/b, 38106 Braunschweig — [3]Technische Universität Braunschweig, Universitätsplatz 2, 38106 Braunschweig

Polycyclic aromatic hydrocarbons are suitable to be used in a single-photon source at cryogenic and room temperatures, respectively. One prerequisite is their embedment in a stabilizing solid matrix protecting them from oxygen and thermal induced bleaching effects. We report a method based on a high temperature and high vacuum deposition procedure allowing for a controllable growth of single layers of dibenzoterrylene (DBT) molecules. They are placed between several monolayers of C60-fullerenes, which are forming the protection against the environmental conditions. An absorption spectrum of this composite was measured, revealing a linear superposition. Raman spectroscopy measurements proved that the DBT molecules were still intact after being deposited. First experiments in a self-built confocal laser scanning microscope did not show any emission at all, indicating a quenching behavior of the molecule after being evaporated. Thermal annealing could cancel out these quenching and an emission of DBT layers was detected. Further investigations will be presented at the conference.

Q 59.61 Thu 16:30 Empore Lichthof

Optimizing silicon vacancies in silicon carbide through nanophotonic integration — •Di Liu[1], Öney Soykal[2], Jawad Ul-Hassan[3], Florian Kaiser[4], Petr Siyushev[1], and Jörg Wrachtrup[1] — [1]University of Stuttgart and IQST, Germany — [2]Booz Allen Hamilton, USA — [3]Linköping University, Sweden — [4]LIST, Luxembourg

The silicon vacancy (V_{Si}) in silicon carbide (SiC) is an emerging spin qubit for quantum computing and quantum network applications, due to its excellent spin-optical properties and progressive nanophotonic integration. A fully scalable application requires a complete understanding of the system's internal spin dynamics in order to further engineer cavity-emitter coupling. In this work, we unravel relevant radiative and non-radiative transition rates of V_{Si} in 4H-SiC. They allow evaluation of several crucial parameters such as the quantum efficiency for estimation of the desired Purcell enhancement factor or the radiative transition cyclicity defining the maximally achievable emission rate.

We also show our latest results on integrating V_{Si} centers in nanophotonic waveguides, including direct waveguide-to-fiber coupling in cryogenic environment. This technique allows us to boost the platform efficiency towards relevant applications in quantum communication and computation.

Q 59.62 Thu 16:30 Empore Lichthof

3D Printed Optical Waveguide Structures with Microdiamonds containing NV Centers — •Marina Peters[1,2], Adrian Abazi[2], Daniel Wendland[2], Tim Buskasper[2], Lara Lindloge[1], Markus Gregor[1], and Carsten Schuck[2] — [1]Department of Engineering Physics, FH Münster, Germany — [2]Department for Quantum Technology, University of Münster, Germany

Quantum technology holds great potential for novel communication, computation and sensing concepts, however, current approaches do not easily scale to large system size. Integrated photonics offers possibilities to address such scaling challenges by leveraging modern nanofabrication processes for implementing complex nanophotonic circuitry. Here we show how nitrogen vacancy centers in diamond, as a prototypical quantum system, can be embedded into optical waveguides that allow for optical excitation and fluorescence collection. We achieve this by employing a lithographic positioning technique for microdiamonds on a silicon chip, which are subsequently integrated into polymer waveguides, produced in 3D direct laser writing. Our method allows for producing hundreds of devices with waveguide-integrated quantum systems on a chip, which can be addressed and read out via optical fiber arrays.

Q 59.63 Thu 16:30 Empore Lichthof

Integration and coupling of quantum emitters in 2D materials to laserwritten waveguides — •Josefine Krause[1], Simone Piacentini[2], Mostafa Abasifard[1], Roberto Osellame[2], Giacomo Corrielli[2], and Tobias Vogl[1,3] — [1]Institute of Applied Physics, Albert-Einstein-Str. 15, 07745 Jena, Germany — [2]Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR), Piazza Leonardo da Vinci 32, 20133 Milano, Italy — [3]Fraunhofer-Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

The practical application of quantum optics, for example in satellite-based quantum communication, requires the miniaturization of optical components into small devices. A hybrid solution is to integrate quantum emitters hosted in layered two-dimensional (2D) materials onto a photonic chip containing femtosecond laser-written waveguides. Emitters in 2D materials, such as hexagonal boron nitride, are suitable photon sources because of their high photon extraction efficiency due to the material's thinness. We demonstrate a deterministic transfer of an exfoliated tungsten disulfide emitter, employed as a test material for its bright fluorescence at room temperature, onto the front face of a waveguide through a viscoelastic stamping technique. The spectral emission properties of the integrated flake were maintained after the integration and coupling through the waveguide. Furthermore, with the goal of space-based applications, we successfully qualified different miniaturized photonic chips in their mechanical robustness during vibration and shock exposure imitating a rocket launch.

Q 59.64 Thu 16:30 Empore Lichthof

Green's function calculations for two-dimensional arrays of molecular emitters — •Davide Torriglia, Daniel M. Reich, and Christiane P. Koch — Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany

Collective excitations of atomic or molecular arrays have recently attracted a lot of interest in quantum optics as a tool to control the propagation, scattering and storage of light fields.

In this project, we aim to describe the coupling of a two-dimensional molecular array with a quantized light mode and investigate the effect of a graphene substrate on the collective state of the molecules.

As a first step towards this, we calculate the dyadic Green's function for various geometries to describe the propagation of the electromagnetic field classically according to Maxwell's equations.

Employing the resulting Green's functions in quantum mechanical simulations, we aim to directly account for the field-propagation effects on molecular arrays in complex geometries, such as those used in the generation of polaritons in modern experiments.

Q 59.65 Thu 16:30 Empore Lichthof

Influence of nonlocal and dispersive material response on fields of metallic plasmons — •Gino Wegner[1,2], Dan-Nha Huynh[1], Bill Antonio Bernhardt[1], Francesco Intravaia[1], and Kurt Busch[1,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, AG Theoretische Optik & Photonik, 12489 Berlin, Germany — [2]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max- Wien-Platz 1, 07743 Jena, Germany — [3]Max-Born-Institut, 12489 Berlin, Germany

Based on the insight that using (noble) metallic nanostructures or -features as subtrates for molecules, can significantly boost the Raman signal of nearby molecules due to plasmonic resonances, we investigate the fields of the latter in the vicinity of the metal surface. Based on established material models for the conduction-electronic response to light, we perform analytical Mie calculations as well as numerical simulations employing the Discontinuous Galerkin Time Domain method. The role of nonlocal and dispersive response is critically examined always keeping in mind the intertwining with geometrical features of the subtrates. For a selection of geometries, this study sheds light on pecularities, that have to be kept in mind, when designing metallic substrates for Surface Enhanced Raman Scattering/Spectroscopy.

Q 59.66 Thu 16:30 Empore Lichthof

Design of metasurface for carbon dioxide reduction photocatalysis — •Ning Lyu[1,2], Zelio Fusco[2], Fiona Beck[2], and Christin David[1] — [1]Institute of Condensed Matter Theory and Optics, Abbe Center of Photonics, Friedrich Schiller University of Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]School of Engineering, Australian National University, Acton ACT 2601, Australia

As artificial photosynthesis, the photocatalytic reduction of CO_2 addresses the emission of greenhouse gases by converting them back to organic fuels with solar energy. These redox reactions include multiple electron transfer processes and various products were generated vas separated reaction pathways simultaneously, such as formic acid, formaldehyde, methanol, methane, and some higher hydrocarbons products. Therefore, it is challenging to have a highly efficient, stable conversion of a selected single product. Metasurface with a large surface-to-volume ratio promote the concentration of hot electrons in the active site on surface and have a great potential in photocatalysis and co-catalysis applications.

We investigate how TiO_2 metasurfaces with nanopillars (NPs) and hollow nanotubes (NTs) affect selected pathways of CO_2 reductions in their optical properties with the Finite Element Method (FEM). Polarization- and angle-sensitive resonances were designed to overlap with selected reaction pathways using asymmetric pitches. By changing the polarization, the absorption efficiency for selected pathways remained at approximately 90% under the solar spectrum, while other pathways varied from about 96% to only 48%.

Q 59.67 Thu 16:30 Empore Lichthof

An Automated Setup for Single-Photon Fluorescence Microscopy Measurements — •Raphael V. Wichary, Matthias Nuss, and Tobias Brixner — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

We present a setup with automated beampath selection to perform ultrafast nonlinear fluorescence microscopy at the single-photon level in a diffraction-limited focus. Pneumatically movable mirrors built into an optical cage system enable quick and reliable changes in the beam path with accurate position reproducibility. The setup includes motorized waveplates for full excitation polarization control with a laser spectrum ranging from 675 nm to 810 nm. Incorporation of a TWINS interferometer [1] enables spectrally resolved measurements of single quantum emitters. Detection is handled either by avalanche photodiodes or by a superconducting nanowire single-photon detector (SNSPD). A Hanbury-Brown–Twiss Interferometer enables verification of anti-bunched photon statistics.

[1] D. Brida et al., Opt. Lett., 37, 3027-3029 (2012)

Q 59.68 Thu 16:30 Empore Lichthof

Quantum coherent interactions between electron vortices and chiral optical near-fields — •Neli Streshkova and Martin Kozák — Department of Chemical Physics and Optics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, CZ-121 16 Prague, Czech Republic

In the recent years new possibilities of shaping free electron beams into the so-called vortex beams have emerged. They hold the promise for many applications in electron microscopy. Specifically, electron vortex beams could be used as a sensitive probe for monitoring the optical near-fields, which emerge around chiral nanostructures under laser light illumination, with near nanometer precision.

Here we present numerical simulations of the inelastic interaction between electron vortex beams and chiral optical near-fields. Initially, the electron wavefunction is modulated via inelastic ponderomotive scattering induced by the interference of two optical waves, one of which is an optical vortex wave carrying orbital angular momentum (OAM). The OAM is transferred to the electron beam, which then interacts with a chiral optical near-field of a golden nanosphere excited by circularly polarized optical field. This interaction leads to changes in the electron spectrum in dependence on the amplitude of the near-field, phase relation between the near-field and the modulating fields and the interplay between the helicity of the beam and the near-field itself. Such interaction scheme will in future allow full reconstruction of the optical and plasmonic near-field distribution of various nanostructures including both the amplitude and the phase.

Q 59.69 Thu 16:30 Empore Lichthof

Scattering of free electrons by optical fields and all-optical method for electron pulse characterization — •Kamila Moriová and Martin Kozák — Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 12116 Prague 2, Czech Republic

Free electrons can scatter of a standing light wave formed by two counter-propagating optical beams of identical frequency in vacuum. The coherent reflection of electron wave at periodic ponderomotive potential of the optical standing wave was first proposed by Kapitza and Dirac in 1933 [1] and it was experimentally demonstrated in 2001 [2]. The Kapitza-Dirac-like diffraction was also theoretically described for more general case with two counterpropagating light waves at different frequencies [3]. In this contribution we discuss different regimes of the interaction between electrons and light fields. Further we study the application of the classical regime of electron scattering at an optical standing wave formed by pulsed laser fields for full characterization of femtosecond electron pulses in an electron microscope [4], which is crucial for ultrafast pump-probe experiments with electron probes. [1] Kapitza, P. L. and Dirac, P. A. M. Proc. Camb. Phil. Soc. 29, 297-300 (1933). [2] Freimund, D. L. et al. Nature 413, 142 (2001) [3] Smirnova, O. et al. Phys. Rev. Lett. 92, 223601 (2004) [4] Hebeisen, C. T. et al. Opt. Express 16, 3334-3341 (2008)

Q 59.70 Thu 16:30 Empore Lichthof

Rapid Dilution Mass Photometry — •Carla M. Brunner[1], Emanuel Pfitzner[2], and Philipp Kukura[2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Department of Chemistry, University of Oxford

Mass Photometry (MP) is an optical method based on interferometric scattering microscopy that enables label-free detection of single proteins in solution based on their scattering contrast. Multiple species in a heterogeneous solution can be differentiated by their molecular mass and consequently, binding affinities can be determined. The study of weak interactions calls for high sample concentrations on the order of μM whereas MP requires low concentrations in the nM range.

Developing a rapid dilution method, we explored how the application of MP can be extended beyond these current constraints. Using microcapillaries, we show that we can inject high concentration solutions of transferrin and the IgG antibody 17b into a buffer medium whereupon the sample is diluted by several orders of magnitude within seconds, maintaining the possibility of single-particle detection and the capability to reliably distinguish different species. Nevertheless, carrying out further experiments with a wider range of protein species revealed that some improvements to the setup are required in order to be able to use

our methodology more broadly. Measurements performed with HspB1 showed that aggregation of proteins in the capillary tip inhibits the precise determination of mass distributions. A careful investigation of our findings allowed us to pin down current limitations and suggest necessary modifications.

Q 59.71 Thu 16:30 Empore Lichthof

The squeeze laser — •Axel Schönbeck, Jan Südbeck, Jascha Zander, Dieter Berz-Vöge, Pascal Gewecke, Malte Hagemann und Roman Schnabel — Institut für Laserphysik der Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

An increasing number of laser-based measurements in metrology are performed at the quantum-noise limit. Squeezed light helps to overcome this limit. For example, as of 2019, all gravitational-wave observatories (GWOs) worldwide use squeezed vacuum states of light.

"Squeeze laser" is a well-motivated name for what is often referred to as a "squeezed light source". Squeezed light is generated in a laser resonator by parametric down-conversion. The laser's output modes have a large coherence time and are in a near-perfect TEM00 mode. We are launching a spin-off from UHH that will offer these squeeze lasers. Which applications benefit from them?

The squeeze laser is a valuable tool for research laboratories. It is required for one-sided device-independent quantum key distribution (QKD) [Nature Commun. 6, 8795 (2015)] and enables a new technique for absolute calibration of photo sensors [Phys. Rev. Lett. 117, 110801 (2016)]. Measurement-based optical quantum computing requires squeezed states [Science 366, 369-372 (2019)]. The squeeze laser can improve industrial laser Doppler vibrometers in environments with low optical losses [Review of Scientific Instruments 87, 102503 (2016)] [Quantum Sci. Technol. 8, 01LT01 (2022)]. It is also beneficial in the detection and imaging of biological cells and macromolecules [Nature Photon. 7, 229-233 (2013)].

Q 59.72 Thu 16:30 Empore Lichthof

Simulations with IfoCAD for tilt-to-length coupling characterization in LISA — •Rodrigo García Álvarez, Megha Dave, Gerhard Heinzel, and Gudrun Wanner — Albert Einstein Instiüt, Hannover, Germany

A major contributor of noise in LISA is the so-called tilt-to-length coupling (TTL). This is the path length signal noise induced by angular and lateral jitters in an interferometric setup. Various TTL noise simulations conducted using IfoCAD, an in-house interferometry analysis tool are presented. These simulations include TTL noise in the test mass interferometers and the inter-satellite interferometers, caused by the jitter of the transmitting and receiving spacecraft. The status of IfoCAD simulations using LISA's latest optical design is included.

Q 59.73 Thu 16:30 Empore Lichthof

Characterization of laser noise with an optical fiber interferometer composed of a 3x3 fiber coupler — •Robin Klöpfer[1,2], Francesca Celine Catalan[1], Ralf Albrecht[1], Annika Belz[2], Harald Kübler[2], Robert Löw[2], Gareth Lees[1], and Tilman Pfau[2] — [1]AP Sensing GmbH, Herrenberger Straße 130, 71034 Böblingen, Germany — [2]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Over the past few decades, fiber-based sensors have been widely deployed in different areas. Distributed acoustic sensing (DAS) in particular has been an important tool for infrastructure monitoring and seismic activity detection. A DAS device sends coherent light into an optical fiber and evaluates the Rayleigh backscattering to monitor strain and acoustic signals over long distances in real time. Because of the high sensitivity of DAS, it is important to ensure a stable optical architecture, starting with a low-noise light source.

Here we characterize the phase and frequency noise of narrow-linewidth lasers using a 120° phase difference unbalanced Michelson interferometer composed of a 3x3 optical fiber coupler. This Michelson interferometer is capable of direct as well as wavelength- and polarization-independent extraction of the differential phase of the incoming laser light, without the need for noise models.

In addition, laser noise measurements are complemented by DAS performance evaluation to identify the most suitable laser for future sensor performance improvements.

Q 59.74 Thu 16:30 Empore Lichthof

Bright Squeezed Light Generation and Quantum Correlation Measurements — •Jasper Venneberg, Henning Vahlbruch, and Benno Willke — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) und Institut für Gravitationsphysik, Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

State-of-the-art, high-precision metrology experiments like gravitational wave detectors require carefully stabilized laser sources with exceptionally low relative power noise (RPN). The RPN is fundamentally quantum noise limited by the relative shot noise (RSN) for classical states of light. As the RSN scales inversely with the square root of the optical power, it can be reduced by increasing the power, i.e., making the laser "brighter". However, this poses various technical challenges and cannot be scaled indefinitely. Thus, additionally "squeezed" states of light can be applied to reduce the RPN below the classical quantum noise limit. This project investigates methods to generate high-power, sub-relative-shot-noise (or "bright squeezed") light. Also, the quantum correlation measurement technique is investigated as an alternative to traditional power noise sensing by correlating two photodetector signals. As presented, this method is capable of sub-shot noise measurements and could serve as a bright squeezing sensor.

Q 59.75 Thu 16:30 Empore Lichthof

Development and characterization of a 2D THz-imaging system based on a 3D printed telecentric f-theta-lens — •Viola-Antonella Zeilberger[1], Konstantin Wenzel[1], Sarah Klein[2], Martin Traub[2], Robert B. Kohlhaas[1], and Lars Liebermeister[1] — [1]Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany — [2]Fraunhofer Institute for Laser Technology ILT, Steinbachstraße 15, 52074 Aachen, Germany

In recent years, terahertz (THz) time-domain spectroscopy (TDS) has become an established tool for various applications, of which non-destructive layer thickness measurements and defect localization are of particular interest. These applications require rapid 2D imaging. Currently, 2D THz imaging is realized by translating either the single point sensor or the sample, which limits the measurement speed. In this work, we present a THz scanning system based on mechanical beam steering by a motorized gimbal mirror and a telecentric f-theta lens. This system contains a commercial THz-TDS system with a photoconductive THz transceiver as the sensor head. The lens fabricated by a 3D printer using a cyclic olefin copolymer (TOPAS) is designed to scan an area of 1.5 cm x 1.5 cm. We characterize this lens by investigating its focusing properties, the f-theta distortion, and scattering losses caused by the 3D printing process. We find that our scanning system offers diffraction-limited imaging up to 2 THz and satisfies the f-theta condition very well. Hence, this approach offers simple, cost-effective THz-imaging with the potential for high scanning rates.

Q 59.76 Thu 16:30 Empore Lichthof

Laser Power Stabilization via Radiation Pressure — •Graziano Pascale, Marina Trad Nery, and Benno Willke — Max Planck Institute for Gravitational Physics (AEI), Hannover

This work reports a new scheme for laser power stabilization in which the power fluctuations of a laser beam are detected via the radiation pressure they produce in a suspended mirror. The ultimate goal of this experiment is to demonstrate an improved technique for power stabilization that can be implemented in the future generations of Gravitational Wave Detectors (GWDs). Most of the current stabilization techniques rely on sensing a small fraction of the laser power by a photodetector. These techniques are fundamentally limited by the high relative shot noise in the photodetector, which couples as sensing noise in the feedback loop.

To overcome this limit, the technique presented on this poster consists on sensing the full beam power of the laser via radiation pressure in a highly reflective micro-oscillator mirror. A proof of principle experiment has been successfully demonstrated in the past years and now an upgraded version is being setup. A key component of the current experiment is a novel micro-oscillator mirror with a spring constant smaller than 10-5 N/m and that might withstand 4 W of power. With the experiment presented in this poster, we want to demonstrate a relative power noise below 10^(-9) Hz^(-(1/2)) at frequencies around 10 Hz, which might be required in future GWDs.

Q 59.77 Thu 16:30 Empore Lichthof

Influence of Temperature and Salinity on the Spectral Characteristics of Brillouin-Scattering in Water — •Daniel Koestel and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, 64289 Darmstadt, Germany

In our group we are developing a LiDAR-system for remote sensing the temperature and salinity in the ocean upper-mixed layer (~100m depth). We successfully demonstrated the functionality of this setup with a temperature resolution of up to 0.07°C and a depth resolution of up to 1m [1]. Both, spectral Brillouin shift and Brillouin linewidth (FWHM), depend on temperature and salinity. The spectral shift dependency of said parameters has already been studied extensively in the past [2,3]. This contribution aims to bring light to the less researched linewidth dependency on temperature and salinity [4]. For this purpose, we generated spontaneous Brillouin-scattering at 530nm in water in a laboratory environment at different temperatures and salinities. We will present our latest results and discuss further steps in the development. [1] A. Rudolf, Th. Walther, "Laboratory demonstration of a Brillouin lidar to remotely measure temperature profiles of the ocean", Opt. Eng. 53(5) (2014). [2] K. Schorstein, E. S. Fry, and Th. Walther, "Depth-resolved temperature measurements of water using the Brillouin lidar technique", Appl. Phys. B 97(4), 931-934 (2009). [3] E. S. Fry et al., "Remote sensing of the ocean: measurement of sound speed and temperature", Proc. SPIE (1998). [4] E. S. Fry et al., "Temperature dependence of the Brillouin linewidth in water", J. Modern Opt. 49(3-4), 411-418 (2002).

Q 59.78 Thu 16:30 Empore Lichthof

Novel tunable cw UV laser system for laser cooling of bunched relativistic ion beams — •Jens Gumm, Jonas Moos, and Thomas Walher — TU Darmstadt

Experiments with highly charged ions at relativistic energies are of great interest for many atomic and nuclear physics experiments at accelerator facilities. In order to decrease the longitudinal momentum spread and emittance, laser cooling has proven to be a powerful tool. In this work, we present a cw UV laser system operating at 257.25 nm for ion beam cooling at the ESR at GSI. The laser system will be used to minimize the final ion beam momentum spread and, therefore, the ion bunch length.
The laser can be scanned mode-hop free, via two SHG stages, over 20 GHz with a 50 Hz scan rate. In our latest measurements, we achieve a power of 1.7 W in the UV regime employing a novel elliptical focussing cavity to reduce the degradation effect in BBO.

Q 59.79 Thu 16:30 Empore Lichthof

A pre-stabilized 1550 nm laser source for the ETpathfinder — •Nicole Knust, Fabian Meylahn, and Benno Willke — Leibniz Universität Hannover / Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Callinstr. 38, 30167 Hannover, Germany

The ETpathfinder is a new facility for testing technologies for the future third-generation gravitational wave observatory called Einstein Telescope. Three of the six interferometers of the Einstein Telescope are proposed to use silicon mirrors at a cryogenic temperature of about 10 K to reduce thermal noise. For compatibility with the new mirror material silicon, a shift to longer wavelengths than the currently used 1064 nm is required. The ETpathfinder will support the investigation of the potential of longer wavelengths in combination with silicon mirrors and the cryogenic cooling of an interferometer. Here we present the frequency and power stabilized laser source for the ETpathfinder with a wavelength of 1550 nm. In our design, the beam of a low-noise, low-power external cavity diode laser is amplified to 10 W output power in two stages. To reduce the beam pointing and higher order mode content, the beam is filtered by an optical cavity. Active, multiple path, and high-bandwidth laser power and frequency stabilizations are implemented to achieve the laser stability needed for use in gravitational wave detectors.

Q 59.80 Thu 16:30 Empore Lichthof

Laser noise in interferometric gravitational wave detectors — •Robert Fabian Maciy — Callinstraße 38, 30167 Hannover — Prinz-Albrecht-Ring 40, 30657 Hannover

This poster presents simulations of laser noise requirements for the laser source of future interferometric gravitational wave detectors, especially for the Einstein Telescope. The Einstein Telescope is a third generation gravitational wave detector that is currently in the design phase and is anticipated to achieve higher sensitivity over a wider frequency range compared to second generation gravitational wave detectors like Advanced LIGO by using longer interferometer arms and advanced experimental techniques. An understanding of how laser frequency and power noise couples to the detector output is crucial to calculate the stringent requirements for the laser system and the optics as well as to possible optimize the interferometer and laser design.

On this poster we will show the results from analytical and numerical calculations of the transfer functions of laser noise propagating through individual optical subsystems and the complete interferometer. As the detector is a complex instrument we will present an intuitive description of noise coupling at different complexity levels. Finally a initial requirement for the stability of the laser source for the Einstein Telescope is shown and discussed.

Q 60: Photonics IV

Time: Friday 11:00–12:45 Location: A320

Q 60.1 Fri 11:00 A320

stimulated Brillouin scattering in chiral photonic crystal fibre — •Xinglin Zeng[1], Philip Russell[1], and Birgit Stiller[1,2] — [1]Max-Planck institute for the science of light — [2]Department of Physics, Friedrich-Alexander-Universität

Stimulated Brillouin scattering (SBS) in optical fibres, in which guided light is parametrically reflected by coherent acoustic phonons, provides a powerful and flexible mechanism for controlling light. The recent advent of chiral photonic crystal fibres (PCF) has been shown to robustly preserve optical modes carrying circular polarization states and optical vortices over long distances, allowing investigation of nonlinear processes in the presence of chirality. Here, we report the topology-selective SBS effect in chiral PCF, demonstrate an optical vortex Brillouin laser and a reconfigurable nonreciprocal vortex isolator based on this novel effect. This work opens up new perspectives in Brillouin scattering, with potential interest in many areas, for example, quantum information processing, optical tweezers and telecommunications.

Q 60.2 Fri 11:15 A320

Complex aspherical singlet and doublet microoptics by grayscale 3D printing — •Leander Siegle, Simon Ristok, and Harald Giessen — 4th Physics Institute, University of Stuttgart

We demonstrate grayscale 3D printed aspherical singlet and doublet microoptical components and characterize and evaluate their excellent shape accuracy and optical performance. The typical two-photon polymerization (2PP) 3D printing process creates steps in the structure which is undesired for optical surfaces. We utilize two-photon grayscale lithography (2GL) to create step-free lenses. To showcase the 2GL process, the focusing ability of a spherical and aspherical singlet lens are compared. The surface deviations of the aspherical lens are minimized by an iterative design process, and no distinct steps can be measured. We design, print and optimize an air-spaced doublet lens with a diameter of 300 μm. After optimization, the residual shape deviation is less than 100 nm and 20 nm for the two lenses, respectively. We examine the optical performance with an USAF 1951 resolution test chart to find a resolution of 645 lp/mm.

Q 60.3 Fri 11:30 A320

3D lithography for single-photon level spectroscopy with superconducting detectors — •Johanna Biendl, Maximilian Protte, Timon Schapeler, Thomas Hummel, and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

Wavelength is a characteristic property of light, the study of which is a crucial technique in many areas of physics. However, measuring wavelength at the single-photon level is a challenging task. Superconducting detectors have shown excellent single photon counting capabilities, however they are typically broadband devices. We aim to combine the advantages of superconducting single-photon detectors with spectrally selective elements at the microscale under cryogenic operating conditions. Using 3D lithography, we fabricated an array of Fabry-Pérot etalons that encodes the spectral information of incident light by generating a unique transmission pattern. By measuring these transmission spectra with superconducting nanowire single-photon detectors, we demonstrated functionality at the single-photon level. The combination of the etalon array with superconducting detectors will therefore enable a reconstructive single-photon spectrometer that can be operated in the near-infrared wavelength range.

Q 60.4 Fri 11:45 A320

Noise characterization of crystalline AlGaAs coatings for ultra-stable optical resonators — •Chun Yu Ma[1], Jialiang Yu[1], Sofia Herbers[1], Thomas Legero[1], Daniele Nicolodi[1], Fritz Riehle[1], Steffen Sauer[2], Dhruv Kedar[3], John M. Robinson[3], Eric Oelker[4], Jun Ye[3], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Institut für Halbleitertechnik and LENA, Technische Universität Braunschweig, Germany — [3]JILA, NIST and University of Colorado, Boulder, Colorado, USA — [4]University of Glasgow, UK

Brownian thermal noise of highly reflective dielectric coatings fundamentally limits the frequency stability of state-of-the-art ultra-stable lasers. Crystalline AlGaAs mirror coating with low mechanical loss is a promising candidate to reduce this limit. However, our recent measurements at cryogenic temperatures have shown novel noise sources in AlGaAs mirrors beyond their thermal noise level [J. Yu et al., arXiv:2210.15671 (2022) and D. Kedar et al., arXiv:2210.14881 (2022)].

In this work, we present a new investigation on the novel noise sources in AlGaAs mirrors in a room temperature ultra-stable resonator and give an update on our measurement at cryogenic temperatures. Our work provides insight into the predicted and actual noise limits set by these coatings.

We acknowledge support by the Project 20FUN08 NEXTLASERS, which has received funding from the EMPIR programme cofinanced by the Participating States and from the European Union's Horizon 2020 Research and Innovation Programme.

Q 60.5 Fri 12:00 A320

Spectral tailoring of quasi-phase-matched nonlinear processes in Ti:LiNbO$_3$ waveguides using microheaters — •Jonas Babai-Hemati, Felix vom Bruch, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Nonlinear optical conversion processes, such as second harmonic generation (SHG) or parametric down-conversion are at the heart of many quantum optic applications. Various efficient devices have been demonstrated using periodically poled Ti-indiffused waveguides in LiNbO$_3$ (PPLN). Their performance, however, is often limited by inhomogeneities induced by an imperfect fabrication. We demonstrate that this problem can be mitigated by counteracting the inhomogeneities by a distinct temperature profile along the waveguide. Here, we theoretically and experimentally investigate a cascade of microheaters, inducing specifically tailored temperature profiles to improve the performance of an SHG-process. With an optimized temperature profile, we could modify the phase-matching resulting from nonuniform domain inversion or varying waveguide cross-section towards ideal spectra. Furthermore, our method also opens new possibilities to tailor spectra of nonlinear optical processes, allowing for highly efficient and tuneable generation of single photons.

Q 60.6 Fri 12:15 A320

Cryogenic Integrated Nonlinear Optics in Lithium Niobate — •Nina Amelie Lange, Jan Philipp Höpker, Maximilian Protte, Dominik Kostiuk, and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

We demonstrate the operation of a nonlinear waveguide at cryogenic temperatures. We investigate the cryogenic performance of Second Harmonic Generation (SHG) and Spontaneous Parametric Down-Conversion (SPDC) in a titanium-indiffused periodically poled lithium niobate waveguide. We show that the nonlinear performance behaves as expected and we can describe the temperature dependent changes very well. Although we change the operation temperature by nearly two orders of magnitude, the SHG process and the SPDC single-photon source remain fully functional.

While SHG and SPDC are typically investigated under ambient conditions, we show that our nonlinear waveguide is compatible with the demanding operation conditions of cryogenic integrated components. The realization of the cryogenic nonlinear processes paves the way for developing novel integrated quantum experiments, for example by combining SPDC sources together with superconducting detectors.

Q 60.7 Fri 12:30 A320

Tunable niobium-based plasmonic superconducting photodetectors for the near- and mid-IR — •Sandra Mennle, Philipp Karl, Monika Ubl, Ksenia Weber, Pavel Ruchka, Mario Hentschel, Philipp Flad, and Harald Giessen — 4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

In the last few years, photon-based applications such as quantum technologies have become a growing field of research. In particular, highly sensitive photodetectors in the near- and mid-IR spectral range are of high importance. Superconducting nanowire single photon detectors, utilizing the resistivity change during the transition from the superconducting to the normal conducting phase, have great potential due to their high efficiency and sensitivity.

To enhance the absorption at larger wavelengths in the IR spectral range, a plasmonic perfect absorber geometry can be used, which utilizes an impedance-matched plasmonic resonance in combination with a spacer layer and a reflector.

In this work we present detectors which reach an absorption of over 95% for wavelengths up to 4 μm. In contrast to cavities, our approach exhibits angle independence, thus high-NA optics can be used to decrease the spot size, resulting in even smaller detector areas and therefore faster response.

Another advantage of the plasmonic approach is the large bandwidth. Furthermore, with simple changes of the geometry the resonance can be easily tuned over a wide spectral range.

Q 61: Quantum Optics with Photons II

Time: Friday 11:00–13:00 Location: E001

Invited Talk Q 61.1 Fri 11:00 E001

Quantum Imaging With Nonlinear Interferometers — •Markus Gräfe — Institute of Applied Physics, Technical University of Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany — Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

Exploiting nonclassical state of light allows new imaging and sensing approaches. In particular, nonlinear interferometers enable quantum imaging with undetected light. Here, based on the effect of induced coherence, samples can be probed with light that is not detected at all. Instead, it quantum correlated partner light is is recorded and yields the information of the sample although it never interacted with it. The talk will outline the fundamental concept, recent progress and limits as well as perspectives for biomedical application.

Q 61.2 Fri 11:30 E001

Unfolding the Hong-Ou-Mandel interference between narrowband heralded states — •Kaisa Laiho[1], Thomas Dirmeier[2,3], Golnoush Shafiee[2,3], and Christoph Marquardt[2,3] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Wilhelm-Runge-Str. 10, 89081 Ulm — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen — [3]Friedrich-Alexander-Universität Erlangen-Nürnberg, Department of Physics, Staudtstr. 7/B2, 91058 Erlangen

The Hong-Ou-Mandel (HOM) interference is pivotal for many quantum information and communication applications. In order to drive such quantum optics hardware often spectrally narrowband photonic emitters are required. Lately, parametric down-conversion (PDC) that produces photons in pairs have become a versatile source of twin beams in order to reliably generate heralded states for these purposes.

At high count rates the PDC process produces multiphoton contributions, which are often disregarded in experiments leading to falsified interpretations. Here, we derive the temporal characteristics of the HOM interference between two independent narrowband heralded states emitted via PDC. We consider the effect of the PDC multiphoton contributions and other experimental imperfections such as optical losses and an unbalanced beam splitter ratio. We find out that the multiphoton background can significantly diminish the visibility of the HOM interference dip. Further, the signal-idler cross-correlation turns into a useful figure of merit for the calibration of the photon flux. Our results are important for reaching a high visibility in an experiment.

Q 61.3 Fri 11:45 E001

Interferometric measurement of the quadrature coherence scale using two replicas of a quantum optical state — •Célia Griffet[1], Matthieu Arnhem[1,2], Stephan De Bièvre[3], and Nicolas J. Cerf[1,4] — [1]Centre for Quantum Information and Communication, Ecole polytechnique de Bruxelles, CP 165, Université libre de Bruxelles, 1050 Brussels, Belgium — [2]Department of Optics, Palacký University, 17. listopadu 1192/12, 77146 Olomouc, Czech Republic — [3]Univ. Lille, CNRS, UMR 8524, INRIA - Laboratoire Paul Painlevé, F-59000 Lille, France — [4]James C. Wyant College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA

Assessing whether a quantum state is nonclassical (i.e., incompatible with a mixture of coherent states) is a ubiquitous question in quantum optics, yet a nontrivial experimental task because many nonclassicality witnesses are nonlinear in the state. In particular, if we want to witness or measure the nonclassicality of a state by evaluating its quadrature coherence scale, this a priori requires full state tomography. Here, we provide an experimentally friendly procedure for directly accessing this quantity with a simple linear interferometer involving two replicas (independent and identical copies) of the state supplemented with photon number measurements. This finding, that we interpret as an extension of the Hong-Ou-Mandel effect, illustrates the wide applicability of the multicopy interferometric technique in order to circumvent state tomography in quantum optics.

Q 61.4 Fri 12:00 E001

Photon counting with click detection — •Fabian Schlue[1], Michael Stefszky[1], Vladyslav Dyachuk[1], Suchitra Krishnaswamy[2], Jan Sperling[2], Benjamin Brecht[1], and Christine Silberhorn[1] — [1]Institute for Photonic Quantum Systems (PhoQS), Integrated Quantum Optics (IQO), Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [2]Theoretical Quantum Science, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

Gaining knowledge about the photon-number distribution (PND) of an arbitrary input state is important for improving quantum technologies like quantum simulation and quantum key distribution. However, current photon number resolved (PNR) detectors (e.g. transition edge sensors) have very low response time and operate at millikelvin, compared to click detectors (e.g. superconducting nanowire single photon detectors), which are cheaper, faster and can operate at several kelvin. However, pseudo PNR can be added in a resource-efficient way to click detectors by using time multiplexed detection (TMD).

Here we present a TMD device, based on cascaded beam splitters, that provides a variable amount of pseudo PNR by changing the number of multiplexed time bins. This can be easily done by adding or removing extension modules with fiber connections. Depending on the experimental needs a trade off between lower measurement time or higher PNR can be made. We implement several detectors tailored to different experimental boundary conditions and investigate methods to retrieve the PND from the measured click statistics. In particular, how different approximations impact the reconstruction.

Q 61.5 Fri 12:15 E001

Studying nonclassical states of light generated by conditional measurements using click detectors — •Ananga Mohan Datta[1], Konrad Tschernig[2], Armando Pérez-Leija[2], and Kurt Busch[1,3] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, 12489 Berlin, Germany — [2]CREOL, The College of Optics and Photonics, University of Central Florida, Florida 32816, USA — [3]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

Conditional measurements are a promising way to generate nonclassical states of light [1-2]. Here we use the statistics produced by click detectors [3] to study the quantum states of light generated via conditional measurements on a detuned waveguide coupler. We investigate the states when one input port is excited by a coherent state while a single-photon Fock state is fed into the other port. We then analyze the projected states when several detectors click in one of the output ports. We present the results of the binomial Q_B parameter [4] of the projected state as a measure for the degree of nonclassicality induced by conditional click detection.

[1] M. Dakna et al., *Phys. Rev. A* **55**, 3184 (1997).
[2] T. J. Bartley et al., *Phys. Rev. A* **86**, 043820 (2012).
[3] J. Sperling et al., *Phys. Rev. A* **85**, 023820 (2012).
[4] J. Sperling et al., *Phys. Rev. Lett.* **109**, 093601 (2012).

Q 61.6 Fri 12:30 E001

Interference and Entanglement Generation using Multiport Beam Splitters — •Shreya Kumar[1], Daniel Bhatti[1], Alex E Jones[2], and Stefanie Barz[1] — [1]Institute for Functional Matter and Quantum Technologies and IQST, University of Stuttgart, 70569 Stuttgart, Germany — [2]Quantum Engineering Technology Labs, H. H. Wills Physics Laboratory and Department of Electrical and Electronic Engineering, University of Bristol, Bristol BS8 1FD, UK

Multi-photon entanglement is an integral part of optical quantum technologies. The generation of multi-photon entangled states typically employs the fusion of entangled pairs of photons from several sources. However, each type of state requires a different configuration of the experimental setup and thus, switching between different states can be cumbersome. Here, we demonstrate a simple and versatile scheme to generate different types of genuine tripartite entangled states with one experimental setup. We send three independent photons through a triport beam splitter, known as a tritter, to generate tripartite W, G and GHZ states. Varying the internal input states, for example, polarization, of the photons and post-selecting output combinations with a certain photon number distribution results in the generation of entangled states. We obtain fidelities of 87.33%, 83.42% and 78.84% for the W, G and GHZ states, respectively, confirming successful generation of genuine tripartite entanglement. Our scheme may also be used as a quantum network server, providing resource states to multiple parties to execute quantum protocols.

Q 61.7 Fri 12:45 E001

Twisted N00N states and the quantum Gouy phase — Markus Hiekkamäki, Rafael F. Barros, Marco Ornigotti, and •Robert Fickler — Photonics Laboratory, Tampere University, Tampere, Finland

Shaping the transverse structure of quantum light has attracted a lot of attention in quantum photonics ranging from fundamental studies to quantum information applications. A powerful way to describe any spatial structure in the paraxial limit are orthogonal transverse spatial modes e.g. Laguerre-Gauss modes. Amongst many other things, such spatial structures serve as a versatile testbed for novel complex quantum states.

I will present advanced schemes of spatial-mode modulation and how they can be used to generate spatial-mode N00N states. The latter describes states where N photons are in an extremal superposition between two orthogonal spatial modes. Our results show that such states when realized with twisted photons, i.e. photons carrying OAM, they can be used to achieve super resolving angle measurements. In addition, we studied spatial mode N00N states in connection to a fundamental wave phenomenon, the so-called Gouy phase. It describes the anomalous phase delay of transversely confined waves when propagating through a focus. When probing it in quantum domain, i.e. when probing the quantum Gouy phase we find that it behaves different from classical light waves in terms of phase evolution as well as spatial mode order.

Q 62: Precision Measurements: Gravity II

Time: Friday 11:00–13:00 Location: E214

Q 62.1 Fri 11:00 E214

Optical Zerodur Bench Toolkit for the BECCAL Cold Atom Experiment — •Faruk Alexander Sellami[1], Jean Pierre Marburger[1], Esther del Pino Rosendo[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Tim Kroh[3], Victoria Henderson[3], Patrick Windpassinger[1], and The MAIUS and BECCAL team[1,2,3,4,5,6,7,8,9,10,11] — [1]Institut für Physik, JGU, Mainz — [2]ILP, UHH, Hamburg — [3]Institut für Physik, HU Berlin, Berlin — [4]FBH, Berlin — [5]IQ & IMS, LUH, Hannover — [6]ZARM, Bremen — [7]Institut für Quantenoptik, Universität Ulm, Ulm — [8]DLR-SC, Braunschweig — [9]DLR-SI, Hannover — [10]DLR-QT, Ulm — [11]OHB-SE, Bremen

The NASA-DLR BECCAL experiment will be a facility for the study of BECs of rubidium and potassium atoms in the microgravity environment of the ISS. For the required laser light distribution and intensity control of several light fields to manipulate the atoms we use an optical bench toolkit based on the glass ceramic Zerodur, which has been already successfully operated in sounding rocket experiments. This material has a negligible coefficient of thermal expansion and can withstand the mechanical shocks during rocket launch as well as temperature and pressure fluctuations to guarantee a stable functionality during the multi-year duration aboard the ISS. Multiple tests of several prototypes are presented. Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50 WP 1433, 50 WP 1703 and 50 WP 2103.

Q 62.2 Fri 11:15 E214

An optical dipole trap in a drop tower - the PRIMUS-project — •Marian Woltmann[1], Christian Vogt[1], Sven Herrmann[1], Claus Lämmerzahl[1], and PRIMUS Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM), 28359 Bremen — [2]LU Hannover, Institute of Quantum Optics

The application of matter wave interferometry in a microgravity (μg) environment offers the potential of largely extended interferometer times and thereby highly increased sensitivities in precision measurements, e.g. of the universality of free fall. While most microgravity cold atom experiments use magnetic trapping with an atom chip, the PRIMUS-project develops an optical dipole trap as an alternative source of ultracold atoms in a drop tower experiment. Solely using optical potentials offers unique advantages like improved trap symmetry, trapping of all magnetic sub-levels and the accessibility of Feshbach resonances. We demonstrated Bose-Einstein condensation of Rubidium in a compact setup on ground while now focusing on a fast, efficient preparation in microgravity using time-averaged optical potentials. Within this talk we will give an overview of the experiment and report on the current status and latest results. The PRIMUS-project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50 WM 2042.

Q 62.3 Fri 11:30 E214

Atom interferometry in the transportable Quantum Gravimeter QG-1 — •Nina Heine[1], Pablo Nuñez von Voigt[1], Ludger Timmen[3], Waldemar Herr[2], Christian Schubert[2], Jürgen Müller[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik, Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The transportable Quantum Gravimeter QG-1 is based on the principle of atom interferometry with collimated Bose-Einstein condensates to determine the local gravitational acceleration aiming for an unprecedented level of accuracy $<3\,\mathrm{nm/s^2}$. This talk elaborates on the design and implementation of the interferometry setup into the atom chip based experimental system. An introduction to the measurement concept and studies of the interferometer performance will be presented and put into perspective with perfomance estimates for given experimental parameters.

We acknowledge financial funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 62.4 Fri 11:45 E214

The Hannover Torsion Balance - a test platform for novel inertial sensing concepts — •Christoph Gentemann[1,2], Gerald Bergmann[2,1], Carolin Cordes[1,2], Gerhard Heinzel[2,1], Moritz Mehmet[2,1], and Karsten Danzmann[2,1] — [1]Leibniz Universität Hannover — [2]Max Planck Institute for Gravitational Physics

Current satellite geodesy missions such as GRACE Follow-On are limited at low frequencies by the noise of their accelerometers. These sensors measure non-gravitational accelerations with free-floating test masses in a capacitive housing through capacitance changes. To test new and more sensitive accelerometer designs a setup is desirable that simulates the force-free environment of space in the laboratory.

Suitably designed torsion pendulums can provide such a test bed, since their rotational motion can be designed to have a low resonance frequency and therefore behave approximately force-free in one dimension above said frequency.

In this talk I will present the Hannover Torsion Balance (HTB), which aims at providing a high precision test platform to investigate new optical readout techniques for test mass motion such as deep frequency modulation interferometry. The current status, including test mass sensing and control, will be discussed. In our laboratory these two things are currently based on electrostatic readout and feedback, to provide a sensible comparison with the space-based accelerometers.

Future upgrades to laser interferometric readout of the sensitive degree of freedom will also be discussed.

Q 62.5 Fri 12:00 E214

Deep Frequency Modulation Interferometry for test mass readout — •Stefano Gozzo — Albert Einstein Institute Hannover

The new generation of space-based experiments for gravitational wave detection and geodesy comes with a number of technological challenges. The design of future space-based interferometers will have to comply with sub-pm/*Hz sensitivity requirements at low frequencies while providing multi-fringe dynamic range and minimizing the complexity of the optical set up configuration.

The Deep Frequency Modulation Interferometry (DFMI) technique aims at simplifying the standard interferometric readout by replacing it with an exclusively digital phasemeter. An introduction to the DFMI technique will be given in this talk.

While DFMI allows to reduce the amount of optical component, space-based gravity field recovery missions usually require a two interferometer set up. The unequal length arm nature of space-based interferometers makes them sensitive to frequency noise, so that an additional interferometer for frequency stabilization purposes is needed. In order to minimize the complexity of such an optical set up, we developed a Single Element Double Interferometer (SEDI) design. A single piece optical element hosts an unequal armlength interferometer probing the position of a test mass and an internal reference interferometer.

The combination of a SEDI with a DFMI readout is a promising scheme to achieve minimal optical complexity while complying with the initial sensitivity goal, and its performances are currently being tested in the AEI Hannover laboratories.

Q 62.6 Fri 12:15 E214

Experimental Results on Cavity-Laser-Locking for Future Gravimetric Satellites — •Martin Weberpals, Vitali Müller, Malte Misfeldt, and Gerhard Heinzel — Max Planck Institute for Gravitational Physics, Hannover, Germany

The precise measurement of satellite distance variations in a low earth orbit can reveal the structure of Earth's gravity field, which is directly related to the mass distribution underneath the satellites.

The satellite pairs GRACE (2002-2017) and GRACE Follow-On (2018-) provided monthly maps of Earth's gravity field, which are extremely valuable for climate research and the understanding of mass redistribution processes on Earth. Future missions, in which laser interferometry will be the primary means of determining the inter-satellite range, are currently being prepared.

In this presentation, we give a short overview on the heterodyne laser instrument concept and address our experimental activities conducted so far in supporting European instrument development. We show our setup for achieving a classical Pound-Drever-Hall (PDH) lock, based on commercial RedPitaya devices as an initial stage. We also present the status of our work on an extension to the PDH lock, allowing us to read out the free spectral range of a cavity. This measurement can be used to calculate the absolute laser frequency, which is required to convert ranging phase data into biased inter-satellite distance. In the end, we show how these activities contribute to the development of European Instrument Control Electronics potentially to be used in future missions.

Q 62.7 Fri 12:30 E214

High-Power Laser Beam in Higher-Order Hermite-Gaussian Modes — •Benjamin von Behren[1], Joscha Heinze[2], Nina Bode[1], and Benno Willke[1] — [1]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) and Leibniz Universität Hannover, 30167 Hannover, Germany — [2]School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

The sensitivities of current gravitational-wave detectors are limited around signal frequencies of 100Hz by mirror thermal noise. One proposed option to reduce this thermal noise is to operate the detectors in a higher-order spatial laser mode. This operation would require a high-power laser input beam in such a spatial mode. Here, we discuss the generation of the Hermite-Gaussian modes HG3,3, HG4,4 and HG5,5 using one water-cooled spatial light modulator (SLM) at a continuous-wave optical input power of up to 85W. We report unprecedented conversion efficiencies for a single SLM of about 43%, 42% and 41%, respectively, and demonstrate that the SLM operation is robust against the high laser power. This is an important step towards the implementation of higher-order laser modes in future gravitational-wave detectors.

Q 62.8 Fri 12:45 E214

Laser Welding the 100 g Mirrors for the AEI 10 m Prototype Suspensions with Micrometer Precision — •Juliane von Wrangel[1,2], Steffen Böhme[3], Matteo Carlassara[1,2], Gerd Harnisch[3], Firoz Khan[1,2], Philip Koch[1,2], Tobias Koch[3], Johannes Lehmann[1,2], Harald Lück[1,2], Janis Wöhler[1,2], and David S. Wu[1,2] — [1]Leibniz Universität Hannover — [2]Max-Planck-Institut für Gravitationsphysik, Hannover — [3]Fraunhofer-Institut für Angewandte Optik und Feinmechanik, Jena

The 10 m Prototype facility of the Albert-Einstein-Institute Hannover will measure and surpass the Standard Quantum Limit (SQL) by constructing the Sub-SQL Interferometer in a gravitational wave detector (GWD) like configuration. Compared to a full scale GWD, the 100 g test mass mirrors are relatively lightweight to enhance the quantum radiation pressure noise. To isolate these mirrors seismically, they are designed as triple suspensions. The last pendulum stage is quasi-monolithic to suppress suspension thermal noise. This final stage consists of four 20 um thin glass fibers laser welded to each of the mirrors. The welding procedure needs to be done with micrometer precision due to the small dimensions of the layout to ensure the suspended mirrors to be straight within a pitch angle of < 10 mrad.

In cooperation with the Fraunhofer Institute for Applied Optics and Precision Engineering in Jena, a semi-automated fiber welding machine was designed. For this setup, a CO2 laser is used to cleave and weld the glass fibers with the desired precision. In the future, this technique will also be applicable to other mirror suspensions of similar dimensions.

Q 63: Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)

Time: Friday 11:00–12:45 Location: F107

Invited Talk Q 63.1 Fri 11:00 F107

Coherent multidimensional spectroscopy of an ultracold gas — •Friedemann Landmesser[1], Tobias Sixt[1], Katrin Dulitz[1,2], Lukas Bruder[1], and Frank Stienkemeier[1] — [1]Institute of Physics, University of Freiburg, Germany — [2]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria

Femtosecond coherent multidimensional spectroscopy is demonstrated for an ultracold gas of Li atoms [1]. To this end, Li atoms are cooled in a magneto-optical trap and investigated using a phase-modulation time-domain spectroscopy technique, which is especially beneficial for dilute samples because of its high sensitivity [2]. The technique may offer the possibility to investigate time dependencies on the fs scale and coherent correlations in molecular systems with high frequency and time resolution [3]. Due to its quantum pathway selectivity, the technique is furthermore able to reveal multiphoton processes with specific numbers of interacting particles, as previously demonstrated in multiple quantum coherence experiments of weakly interacting thermal alkali atoms with mean interatomic distances in the micrometer-range [4-7].

[1] F. Landmesser et al., arXiv:2210.03023 (2022).
[2] P. Tekavec et al., J. Chem. Phys. 127, 214307 (2007)
[3] D. M. Jonas, Annu. Rev. Phys. Chem. 54, 425 (2003).
[4] L. Bruder et al., Phys. Rev. A 92, 053412 (2015).
[5] S. Yu et al., Opt. Lett. 44, 2795 (2019).
[6] L. Bruder et al., Phys. Chem. Chem. Phys. 21, 2276 (2019).
[7] B. Ames et al., New J. Phys. 24, 13024 (2022).

Q 63.2 Fri 11:30 F107

Resonance lineshapes in Rydberg atom - ion interactions — •Neethu Abraham and Matthew T Eiles — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

Rydberg molecules, ranging from the so-called "trilobite" molecules to Rydberg macrodimers to Rydberg atom-ion molecules, are a stunning highlight of recent experimental progress in ultracold atomic physics. Various factors can contribute to the decay of such molecules, including radiative decay or associative ionization. One non-radiative mechanism is the non-adiabatic coupling between electronic potential energy curves. We investigate this mechanism here in the Rydberg-ion molecule system using the streamlined version of the R-matrix method to compute the resonant line shapes. We provide a detailed analysis of the profiles and widths of these resonances and characterize them using the Fano-Feshbach lineshape. This shows how non-adiabatic coupling shifts the resonance positions away from the binding energies predicted in the Born-Oppenheimer approximation, and indicates the lifetimes of these states with regard to non-adiabatic decay. We explore these resonances over a range of different principal quantum numbers. Such a study can be relevant to the other types of Rydberg molecules as well.

Q 63.3 Fri 11:45 F107

Experimental investigation of multilevel Autler-Townes spectra — •Jana Bender, Patrick Mischke, Tanita Klas, Florian Binoth, Thomas Niederprüm, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

The Autler-Townes splitting in a strongly coupled two-level-system is a well-known effect in atomic physics. However, actual atomic systems seldom are perfect two-level-systems: Both hyperfine structure and magnetic sublevels result in closely spaced multilevel systems where two individual states can be coupled only for distinct combinations of laser polarization and quantum numbers. The coupling lifts degeneracies and mixes the states, resulting in complex spectra deviating from the symmetrical two-level Autler-Townes splitting.

We experimentally investigate these spectra in a thermal cloud of ^{87}Rb atoms by resonantly coupling the $6P3/2, F = 3$ state to a Rydberg state with varying Rabi frequency. We selectively probe the population of the resulting mixed states with a laser of adjustable polarization.

Our experiments confirm that multilevel effects have to be considered in the Autler-Townes regime. As a general rule, the splitting between peaks is not equal to the Rabi frequency if the coupling strength exceeds the energetic distance of adjacent states.

Q 63.4 Fri 12:00 F107

Exploring the Many-Body Dynamics Near a Conical Intersection with Trapped Rydberg Ions — Filippo Gambetta[1,2], Chi Zhang[3], Markus Hennrich[3], Igor Lesanovsky[1,2,4], and •Weibin Li[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, United Kingdom

— [3]Department of Physics, Stockholm University, 10691 Stockholm, Sweden — [4]Institut für Theoretische Physik, University of Tübingen, 72076 Tübingen, Germany

Conical intersections between electronic potential energy surfaces are paradigmatic for the study of nonadiabatic processes in the excited states of large molecules. However, since the corresponding dynamics occurs on a femtosecond timescale, their investigation remains challenging and requires ultrafast spectroscopy techniques. We demonstrate that trapped Rydberg ions are a platform to engineer conical intersections and to simulate their ensuing dynamics on larger length scales and timescales of the order of nanometers and microseconds, respectively; all this in a highly controllable system. Here, the shape of the potential energy surfaces and the position of the conical intersection can be tuned thanks to the interplay between the high polarizability and the strong dipolar exchange interactions of Rydberg ions. We study how the presence of a conical intersection affects both the nuclear and electronic dynamics demonstrating, in particular, how it results in the inhibition of the nuclear motion.

Q 63.5 Fri 12:15 F107

Diffusive-like Redistribution in State-changing Collisions between Rydberg Atoms and Ground State Atoms — •Markus Exner, Philipp Geppert, Max Althön, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

We report on inelastic collisions between Rydberg and ground state atoms. Our experiment starts with a cloud of ultracold Rubidium atoms in a crossed dipole trap. Using a three-photon excitation scheme, we photoassociate ultralong-range Rydberg molecules with huge bond lengths . These exotic molecular species are formed by a Rydberg atom and ground state atom, where the binding mechanism originates from scattering interaction between Rydberg electron and the ground state atom. We have observed the decay of these molecules in which the ground state atom tunnels toward the Rydberg core. During this collision a state-change of the Rydberg electron takes place. We found a redistribution of population over a wide range of final states. In addition, a decay into different orbital angular momentum states could be observed. These state-changing collisions can be described as a diffusive-like redistribution at short internuclear distances.

Q 63.6 Fri 12:30 F107

The role of Coulomb anti-blockade in the photoassociation of long-range Rydberg molecules — Michael Peper[1,2], Edward Treu-Painter[1], Martin Trautmann[1], and •Johannes Deiglmayr[1] — [1]Universität Leipzig, Germany — [2]Princeton University, Princeton, USA

We present a new mechanism contributing to the detection of photoassociated long-range Rydberg molecules via pulsed-field ionization: ionic products, created by the decay of a long-range Rydberg molecule, modify the excitation spectrum of surrounding ground-state atoms and facilitate the excitation of further atoms into Rydberg states by the photoassociation light. Such an ion-mediated excitation mechanism has been previously called *Coulomb anti-blockade*. Pulsed-field ionisation typically doesn't discriminate between the ionization of a long-range Rydberg molecule and an isolated Rydberg atom, and thus the number of atomic ions detected by this mechanism is not proportional to the number of long-range Rydberg molecules present in the probe volume. By combining high-resolution UV and RF spectroscopy of a dense, ultracold gas of cesium atoms, theoretical modeling of the molecular level structures of long-range Rydberg molecules bound below $n\,^2P_{3/2}$ Rydberg states of cesium, and a rate model of the photoassociation and decay processes, we unambiguously identify the signatures of this detection mechanism in the photoassociation of long-range Rydberg molecules bound below atomic asymptotes with negative Stark shifts.

Q 64: Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)

Time: Friday 11:00–12:45 Location: F303

Invited Talk Q 64.1 Fri 11:00 F303

An elementary network of entangled optical atomic clocks — •Raghavendra Srinivas, Bethan Nichol, David Nadlinger, Peter Drmota, Dougal Main, Gabriel Araneda, Chris Ballance, and David Lucas — University of Oxford

Optical atomic clocks are our most precise tools to measure time and frequency. Precision frequency comparisons between atoms in separate locations can be used to probe the space-time variation of fundamental constants, the properties of dark matter, and for geodesy. Such frequency comparisons on independent systems are typically limited by the standard quantum limit (SQL). Here, we demonstrate the first quantum network of entangled optical clocks using two $^{88}Sr^{+}$ ions separated by a macroscopic distance (2 m), that are entangled using a photonic link. We use this network to perform entanglement-enhanced frequency comparisons beyond the SQL[1]. This two-node network could be extended to additional nodes, to other species of trapped particles, or to larger entangled systems via local operations.

[1] Nichol, Srinivas et al., Nature 609, 689-694 (2022)

Q 64.2 Fri 11:30 F303

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian J. Zawierucha[1], Till Rehmert[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesalnstalt, Braunschweig, Deutschland — [2]2Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

High precision spectroscopy of trapped molecular ions constitutes a promising tool for the study of fundamental physics. Possible applications include the search for a variation of fundamental constants and measurement of the electric dipole moment of the electron. Compared to atoms, molecules offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well- suited for those applications. However, the additional rotational and vibrational degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, optical pumping and state detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy, where a well-controllable atomic ion is co-trapped to the molecular ion, both coupled strongly via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection. Using a Ca ion, we implemented a quantum logic scheme to detect population transfer on a co-trapped spectroscopy ion, induced by a far detuned Raman laser setup. We present the latest progress of the experiment, aiming at high precision quantum logic spectroscopy of single molecular ions.

Q 64.3 Fri 11:45 F303

An aluminum ion clock with 1.1×10^{-18} estimated systematic uncertainty — •Johannes Kramer[1,2], Fabian Dawel[1,2], Marek Hild[1,2], Lennart Pelzer[1], Kai Dietze[1,2], Steven A. King[3], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Oxford Ionics Limited, Begbroke OX5 1PF, United Kingdom

A single trapped $^{27}Al^{+}$ ion is an excellent frequency reference for an optical clock, as it is largely insensitive to external field shifts. Achieved inaccuracies are below the 10^{-18} level and thus make aluminum clocks promising candidates for a re-definition of the SI second and enable for cm-scale height measurements in relativistic geodesy. We estimated the systematic uncertainty budget of PTB's Al^{+} clock using a single $^{40}Ca^{+}$ ion as a sensor. Included in the analysis are shifts by black body radiation, collisions with background gas molecules, residual kinetic energy from uncompensated micromotion and the ac Zeeman shift caused by fast oscillating magnetic fields. The latter shift is mainly induced by the applied radio frequency used to trap the ion. Measurements show that these fields are in the range of a few 10 μT in our trap and are therefore a non-negligible contribution to the systematic frequency uncertainty budget.

Q 64.4 Fri 12:00 F303

Improved limits for the coupling of ultralight bosonic dark matter to photons from optical atomic clock comparisons

— •Melina Filzinger, Martin Steinel, Joshua Klose, Sören Dörscher, Christian Lisdat, Ekkehard Peik, and Nils Huntemann — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Ultralight bosonic dark matter is expected to display coherent-wave behaviour. A hypothetical coupling of such dark matter to photons would lead to oscillations in the value of the fine-structure constant [1]. The frequency of the ${}^2S_{1/2}(F=0) \leftrightarrow {}^2F_{7/2}(F=3)$ electric-octupole transition in ${}^{171}\mathrm{Yb}^+$ is the most sensitive to variations of the fine structure constant among the atomic clocks currently in operation. We compare this frequency to that of the ${}^2S_{1/2}(F=0) \leftrightarrow {}^2D_{3/2}(F=0)$ electric-quadrupole transition of the same ion, as well as to that of the ${}^1S_0 \leftrightarrow {}^3P_0$ transition in ^{87}Sr, both of which feature small sensitivities to variations of α. Based on these long-term measurements, we present improved constraints on temporal variations of the fine-structure constant. In particular, constraints on an oscillation with a specific frequency are translated into constraints on the scalar coupling d_e of bosonic dark matter with a specific mass to photons.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project-ID 274200144 – SFB 1464 DQmat and Project-ID 390837967 – EXC-2123 QuantumFrontiers.

[1] A. Arvanitaki et al., Phys. Rev. D 91, 015015 (2015).

Q 64.5 Fri 12:15 F303

An optical atomic clock based on correlation measurements of a two ion ${}^{40}\mathrm{Ca}^+$ crystal — •Kai Dietze[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1], Fabian Dawel[1,2], Johannes Kramer[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

Trapped ion optical clocks reach high relative frequency accuracies but are often limited by quantum projection noise in their statistical uncertainty, thus requiring long averaging times. The statistical uncertainty can be reduced by increasing the number of ions and/or probing the ion(s) for a longer time with the clock laser. By extending the measurement to entangled states the statistical uncertainty can even surpass the quantum projection noise of classical interrogation protocols [1]. In our scheme classically and quantum correlated quantum states of a two-ion ${}^{40}\mathrm{Ca}^+$ crystal are prepared in a so-called decoherence-free substate (DFS), which is insensitive to linear magnetic field fluctuations [2]. We present the results of these correlation measurements within the DFS, showing near lifetime limited coherence times. Furthermore, we demonstrate the stabilization of our clock laser using these classically correlated states. First steps towards the utilization of entangled states prepared with a Cirac-Zoller gate and the integration in the measurement protocol will be shown.

[1] E.M. Kessler et al., PRL 112, 190403 (2014)
[2] C. Roos et al., Nature 443, 316319 (2006)

Q 64.6 Fri 12:30 F303

Progress of the ${}^{171}\mathrm{Yb}^+$ single-ion optical clocks at PTB — •jian jiang, martin steinel, melina filzinger, ekkehard peik, and nils huntemann — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Clocks based on optical reference transitions of single ions confined in radio-frequency traps or neutral atoms trapped in optical lattices are the most accurate measurement devices ever built. The ${}^2S_{1/2}(F=0) \rightarrow {}^2F_{7/2}(F=3)$ electric octupole transition of a single trapped ${}^{171}\mathrm{Yb}^+$ ion is employed as the reference in our case. In this talk, we report on an improved end-cap ion trap with low-loss insulator material and high thermal conductivity to obtain a homogeneous temperature distribution. A thick gold coating of the electrodes should lead to a low ion heating rate, and a precise evaluation of shifts from residual fields promises a total uncertainty below 1×10^{-18}. For the latter, we make use of the ${}^2S_{1/2}(F=0) \rightarrow {}^2D_{3/2}(F=2)$ electric quadrupole transition of the same ion. This transition can also be used to efficiently cool the ion to the motional ground state and suppress corresponding Doppler shifts.

Q 65: Many-body Physics

Time: Friday 11:00–13:00 Location: F342

Q 65.1 Fri 11:00 F342

Wave-particle duality of many-body quantum states — •Christoph Dittel[1,2,3], Gabriel Dufour[1,2], Gregor Weihs[4], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [3]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg, Germany — [4]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria

We formulate a general theory of wave-particle duality for many-body quantum states, which quantifies how wavelike and particlelike properties balance each other. Much as in the well-understood single-particle case, which-way information – here, on the level of many-particle paths – lends particle character, while interference – here, due to coherent superpositions of many-particle amplitudes – indicates wavelike properties. We analyze how many-particle which-way information, continuously tunable by the level of distinguishability of fermionic or bosonic, identical and possibly interacting particles, constrains interference contributions to many-particle observables and thus controls the quantum-to-classical transition in many-particle quantum systems. The versatility of our theoretical framework is illustrated for Hong-Ou-Mandel-like and Bose-Hubbard-like exemplary settings.

Q 65.2 Fri 11:15 F342

Chiral edge dynamics of ultracold erbium atoms in a synthetic Hall system — Roberto Vittorio Röll, Arif Warsi Laskar, •Franz Richard Huybrechts, and Martin Weitz — Universität Bonn, Deutschland

The study of non-trivial topological phases of matter offers opportunities to produce platforms for interesting physics and plays an important role in the advancement of applications in the realm of quantum computing and information. Research on topologically protected edge states is currently being conducted due to their robustness with regards to smooth changes in the system's geometry. Here we report on the observation of chiral edge dynamics with an ultracold atomic erbium system in a synthetic 2D Hall ribbon, which is spanned by one internal and one external degree of freedom of the atoms. The topological nature of the system is confirmed by observing both closed and skipping orbits, and by determining the local Chern marker.

Q 65.3 Fri 11:30 F342

Ferromagnetism and Skyrmions in the Hofstadter-Fermi-Hubbard Model — •Felix A. Palm[1], Mert Kurttutan[2], Annabelle Bohrdt[3], Uli Schollwöck[1], and Fabian Grusdt[1] — [1]LMU Munich & MCQST, Munich, Germany — [2]Freie Universität Berlin, Germany — [3]Harvard University & ITAMP, Cambridge (MA), USA

Strongly interacting fermionic systems host a variety of interesting quantum many-body states with exotic excitations. For instance, the interplay of strong interactions and the Pauli exclusion principle can lead to Stoner ferromagnetism, but the fate of this state remains unclear when kinetic terms are added. While in many lattice models the fermions' dispersion results in delocalization and destabilization of the ferromagnet, flat bands can restore strong interaction effects and ferromagnetic correlations. To reveal this interplay, here we propose to study the Hofstadter-Fermi-Hubbard model using ultracold atoms. We demonstrate, by performing large-scale DMRG simulations, that this model exhibits a lattice analog of the quantum Hall ferromagnet at magnetic filling factor $\nu = 1$. We reveal the nature of the low energy spin-singlet states around $\nu \approx 1$ and find that they host quasi-particles and quasi-holes exhibiting spin-spin correlations reminiscent of skyrmions. Finally, we predict the breakdown of flat-band ferromagnetism at large fields. Our work paves the way towards experimental studies of lattice quantum Hall ferromagnetism, including prospects to study many-body states of interacting skyrmions and explore the relation to high-Tc superconductivity.

Q 65.4 Fri 11:45 F342

Many-particle interference in the tunneling dynamics of ultracold atoms experiencing dipole-dipole interactions — •Malte Henes[1,2], Andreas Buchleitner[1,2], and Christoph Dittel[1,2,3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [3]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg, Germany

We study how dipole-dipole interactions affect many-particle interference in the tunneling dynamics of ultracold fermionic (^{87}Sr) (or bosonic ^{88}Sr) atoms, in a one-dimensional optical lattice or in an array of optical tweezers. The atoms' tunneling is considered as fully coherent, mediated by a Hubbard-like Hamiltonian, and dipole-dipole interactions, induced by the atoms' $^1S_0 \to {}^3P_0$ clock transition, are modelled through a master equation with a coherent, dispersive, and an incoherent, dissipative part. As a result of the interplay between dipole-dipole interactions and tunneling dynamics, we identify perfectly subradiant (dark) states for fermions, and find that the reduced visibility contrast in the particles' tunneling dynamics is indicative of the particles' partial distinguishability – induced by their dissipative interaction with the electromagnetic environment.

Q 65.5 Fri 12:00 F342

Aubry transition in chains of long-range interacting particles — •Raphaël Menu[1], Jorge Yago Malo[2], Maria Luisa Chiofalo[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universit *at des Saarlandes, D-66123 Saarbr *ucken, Germany — [2]Dipartimento di Fisica Enrico Fermi, Universita di Pisa and INFN, Largo B. Pontecorvo 3, I-56127 Pisa, Italy

The celebrated Frenkel-Kontorova model provides a framework for understanding the onset of structures emerging from the interaction of a periodic crystalline structure with an underlying substrate with competing characteristic lengths. By tuning the depth of the substrate potential, the crystal undergoes a transition from a frictionless sliding on the surface to a pinned state. This is the so-called Aubry transition. While the classical picture of this model is well-understood, its quantum nature is still largely unexplored. Experimental realizations, such as chains of laser cooled trapped ions interacting with a periodic potential, are characterized by repulsive long-range interactions, for which the paradigm of the Frenkel-Kontorova model is only partially applicable.

In this work we analyze theoretically the dynamics at the Aubry transition for a chain of trapped ions interacting via the long-range Coulomb interaction.

Q 65.6 Fri 12:15 F342

Charge pumping in the anomalous Floquet topological insulator with Falicov-Kimball interactions — •Arijit Dutta[1], Tao Qin[2], and Walter Hofstetter[1] — [1]Goethe-Universität Frankfurt, Institut für Theoretische Physik, Frankfurt, Germany — [2]School of Physics and Optoelectronics Engineering, Anhui University, Hefei, Anhui Province 230601, People's Republic of China

The anomalous Floquet topological insulator (AFTI) is a unique phase found in periodically driven systems which hosts topological edge states even when the Chern number of the bulk band is zero. This results in quantized charge pumping in a nanoribbon geometry. Using Floquet-Keldysh DMFT we evaluate the efficiency of pumping in the AFTI phase in presence of Falicov-Kimball (FK) interaction and compare it with the corresponding results in the nonanomalous Floquet topological insulator - the so-called Haldane phase. We further discuss heating issues and relevance to experiments.

Q 65.7 Fri 12:30 F342

Nonlinear Response of Coherently Driven Atomic Arrays in the Discrete Truncated Wigner Approximation — •Christopher Mink and Michael Fleischhauer — University of Kaiserslautern-Landau

We derive a semiclassical approximation for the collective spontaneous and stimulated emission of an ensemble of driven two-level systems based on the discrete truncated Wigner approximation. In the case of totally symmetrical decay ("Dicke model") our method accurately reproduces exact results including width and height of the superradiant burst and population trapping even at small ensemble sizes.

We then study the dynamics of square subwavelength atomic arrays of 14x14 atoms and the non-isotropic emission of photons of initially fully inverted arrays. Furthermore the nonlinear transmissivity and reflectivity in the presence of a classical driving field at varying intensities is determined.

Q 65.8 Fri 12:45 F342

Spin-Holstein Models in Trapped-Ion Systems — •Johannes Knörzer[1], Tao Shi[2], Eugene Demler[3], and Ignacio Cirac[4] — [1]Institute for Theoretical Studies, ETH Zurich, 8006 Zurich, Switzerland — [2]Chinese Academy of Sciences, Beijing 100190, China — [3]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [4]Max Planck Institute of Quantum Optics, 85748 Garching, Germany

In this work, we highlight how trapped-ion quantum systems can be used to study generalized Holstein models, and benchmark expensive numerical calculations. We study a particular spin-Holstein model that can be implemented with arrays of ions confined by individual microtraps, and that is closely related to the Holstein model of condensed matter physics, used to describe electron-phonon interactions. In contrast to earlier proposals, we focus on simulating many-electron systems and inspect the competition between charge-density wave order, fermion pairing, and phase separation. In our numerical study, we employ a combination of complementary approaches, based on non-Gaussian variational ansatz states and matrix product states, respectively. We demonstrate that this hybrid approach outperforms standard density-matrix renormalization group calculations. At the end of the talk, I will give a perspective of interesting applications in quantum simulation.

Q 66: Quantum Metrology (joint session QI/Q)

Time: Friday 11:00–13:00 Location: F428

Q 66.1 Fri 11:00 F428

Super-Resolution Imaging with Multiparameter Quantum Metrology in Passive Remote Sensing — •Emre Köse and Daniel Braun — Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, 72076 Tübingen, Germany

We study super-resolution imaging theoretically using a distant n-mode interferometer in the microwave regime for passive remote sensing, used e.g., for satellites like the "soil moisture and ocean salinity (SMOS)" mission to observe the surface of the Earth. We give a complete quantum mechanical analysis of multiparameter estimation of the temperatures on the source plane. We find the optimal detection modes by combining incoming modes with an optimized unitary that enables the most informative measurement based on photon counting in the detection modes and saturates the quantum Cramér-Rao bound from the symmetric logarithmic derivative for the parameter set of temperatures. In our numerical analysis, we achieved a quantum-enhanced super-resolution by reconstructing an image using the maximum likelihood estimator with a pixel size of 3 (km), which is ten times smaller than the spatial resolution of SMOS with comparable parameters. Further, we find the optimized unitary for uniform temperature distribution on the source plane, with the temperatures corresponding to the average temperatures of the image. Even though the corresponding unitary was not optimized for the specific image, it still gives a super-resolution compared to local measurement scenarios for the theoretically possible maximum number of measurements.

Q 66.2 Fri 11:15 F428

Activation of metrologically useful genuine multipartite entanglement — •Róbert Trényi[1,2,3], Árpád Lukács[1,4,3], Paweł Horodecki[5,6], Ryszard Horodecki[5], Tamás Vértesi[7], and Géza Tóth[1,2,8,3] — [1]Dept. of Theoretical Physics, U. of the Basque Country UPV/EHU, Bilbao, Spain — [2]DIPC, San Sebastián, Spain — [3]Wigner Research Centre for Physics, Budapest, Hungary — [4]Dept. of Mathematical Sciences, Durham University, United Kingdom — [5]International Centre for Theory of Quantum Technologies, University of Gdansk, Gdansk, Poland — [6]Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdansk University of Technology, Gdansk, Poland — [7]Institute for Nuclear Research, Debrecen, Hungary — [8]IKERBASQUE, Bilbao, Spain

In quantum metrology, the usefulness of a quantum state is determined by how much it outperforms separable states. For the maximal metrological usefulness genuine multipartite entanglement (GME) is required. In order to improve the usefulness of a quantum state we consider a scheme of having several of its copies. With this scheme, it is possible to find a large class of practically important entangled states that can achieve maximal metrological performance in the limit of many copies, whereas in the single copy case these states can even be non-useful. Thus, we essentially activate quantum metrologically useful GME. Moreover, this maximal usefulness is attained exponentially fast with the number of copies and it can be achieved by measurements of simple correlation observables. We also give examples of improving the usefulness outside of the above mentioned class.

Q 66.3 Fri 11:30 F428

Quantum metrology with ultracold chemical reactions — Seong-Ho Shinn[1], Uwe R. Fischer[1], and •Daniel Braun[2] — [1]Seoul National University — [2]Eberhard Karls University Tübingen

Classical chemical reactions are routinely used for extremely sensitive detection schemes in chemical, biological, and medical analysis, and have even been employed in the search for dark matter. Now we show that coherent, ultracold chemical reactions harbor great potential for quantum metrology [1]: In an atom-molecule Bose-Einstein condensate (BEC), a weak external perturbation can generate elementary excitations, "reactons", of a reaction field. In an appropriate atom-dominant parameter regime this translates to the coherent creation of molecules which can be selectively detected with modern spectroscopic techniques. This promises to improve the viability of previously proposed BEC-based sensors for gravitational waves and other physical quantities, for which so far no practical read-out scheme could be demonstrated.

[1] Seong-Ho Shinn, Uwe R. Fischer, and Daniel Braun, arXiv:2208.06380

Q 66.4 Fri 11:45 F428

Quantum metrology from randomized measurements — •Satoya Imai[1], Otfried Gühne[1], and Géza Tóth[2,3,4,5] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany — [2]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain — [3]Donostia International Physics Center (DIPC), ES-20080 San Sebastian, Spain — [4]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain — [5]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

A central task in quantum metrology is to consider a parameter encoding on a quantum system and to improve schemes to reach optimal precision. To reach higher precision, precise control of state preparation and favorable measurements may be necessary. In practice, however, unavoidable noise effects, such as magnetic field fluctuations, may affect the estimation accuracy. A key idea to address this situation is to perform a random measurement on the quantum system and access local unitary invariants. This procedure motivates the study of quantum metrology without a common reference frame between several parties. In this talk, we present a systematic method to investigate the estimation sensitivity in the dynamics based on nonlinear interaction Hamiltonians. We show that the well-known Heisenberg scaling is achievable and even better scaling is attainable.

Q 66.5 Fri 12:00 F428

Closed-loop Quantum Optimal Control for Electronic Spins — •Thomas Reisser[1,2], Marco Rossignolo[3,4], Matthias M. Müller[1], Felix Motzoi[1], Fedor Jelezko[3], Simone Montangero[4,5], and Tommaso Calarco[1,2] — [1]Forschungszentrum Jülich GmbH — [2]University of Cologne — [3]Ulm University — [4]Università degli Studi di Padova — [5]INFN, Sezione di Padova

To unlock the full potential of many quantum technologies, quantum optimal control (QOC) algorithms and strategies are used to enhance and enable operations on a quantum system. While some methods depend on simulations and good models of the system, it can be helpful to close the loop with an experiment in order to tweak the given controls for a specific setup. The Quantum Optimal Control Suite (QuOCS) is designed to perform black-box optimization in connection with an arbitrary experiment or simulation. Due to its interface with the experiment control software Qudi [1] is has been used successfully for the optimization of pulses for color centers in diamond and also two-qubit gates with Rydberg Atoms [2]. We show the main features of the QuOCS software package and report on recent developments and applications of QOC on electron spins in crystals with a focus on quantum sensing.

References:

[1] J. M. Binder et al., Qudi: A modular python suite for experiment control and data processing, SoftwareX (2017)

[2] A. Pagano et al., Error budgeting for a controlled-phase gate with strontium-88 rydberg atoms, PRR (2022)

Q 66.6 Fri 12:15 F428

Quantum Wasserstein distance based on an optimization over separable states — •Géza Tóth[1,2,3,4] and József Pitrik[4,5,6] — [1]Theoretical Physics and EHU Quantum Center, University of the Basque Country UPV/EHU, ES-48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), ES-20080 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, ES-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, HU-1525 Budapest, Hungary — [5]Alfréd Rényi Institute of Mathematics, HU-1053 Budapest, Hungary — [6]Department of Analysis, Institute of Mathematics, Budapest University of Technology and Economics, HU-1111 Budapest, Hungary

We define the quantum Wasserstein distance such that the optimization is carried out over bipartite separable states rather than bipartite quantum states in general, and examine its properties. Surprisingly, we find that its self-distance is related to the quantum Fisher information. We discuss how the quantum Wasserstein distance introduced is connected to criteria detecting quantum entanglement. We define variance-like quantities that can be obtained from the quantum Wasserstein distance by replacing the minimization over quantum states by a maximization. We extend our results to a family of generalized quantum Fisher information.

[1] G. Tóth and J. Pitrik, arXiv:2209.09925.

Q 66.7 Fri 12:30 F428

Infrared laser absorption magnetometry with Ensembles of Nitrogen-Vacancy centres — •Felipe Perona[1,2], Julian Bopp[2], Jonas Wollenberg[2], and Tim Schröder[1,2] — [1]Ferdinand-Braun-Institut (FBH), Berlin, Germany — [2]Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany

Magnetometers based on ensembles of Nitrogen-Vacancy (NV) centres have shown sub-nanotesla sensitivities [1]. The applied measurement concept relies on the detection and analysis of the intensity of the NV's red fluorescence, which, under the proper conditions, encodes the value of a magnetic field at the defect location. A less explored approach is using the infrared absorption of the NV centre at 1042 nm as a medium to read its local magnetic environment [2]. This strategy avoids the necessity of implementing high photon collection efficiencies, improves the read-out contrast, and simplifies the sensing setup, allowing a higher degree of integration. In this work, we implement infrared laser absorption magnetometry and demonstrate that such magnetometer can reach high sensitivities. To maximize this sensitivity, we engineer the NV density of our diamonds and optimize it for this task. We integrate the concept into a compact device towards enabling miniaturized, portable magnetometers.

[1] H. Clevenson et al., "Broadband magnetometry and temperature sensing with a light-trapping diamond waveguide", Nat. Phys., 11:5, 2015 [2] V. Acosta et al., "Broadband magnetometry by infrared-absorption detection of nitrogen-vacancy ensembles in diamond", Appl. Phys. Lett., 97:17, 2010

Q 66.8 Fri 12:45 F428

Gradient Magnetometry with Atomic Ensembles — •Iagoba Apellaniz[1], Iñigo Urizar-Lanz[1], Zoltán Zimborás[1,2,3], Philipp Hyllus[1], and Géza Tóth[1,3,4] — [1]Department of Physics, University of the Basque Country UPV/EHU, P. O. Box 644, E-48080 Bilbao, Spain — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Bu-

dapest, Hungary — [4]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain

We calculate precision bounds for estimating the gradient of the magnetic field based on the quantum Fisher information for various types of ensembles, such as for example, a single atomic ensemble with an arbitrary density profile, where the atoms cannot be addressed individually and which is a very relevant case for experiments.

We present a method to find spin states for gradient magnetometry with two spatially separated atomic ensembles based on states for sensing a global phase shift, such as the GHZ state or the Dicke state.

[1] I. Apellaniz et al., Phys. Rev. A, 97 053603 (2018)
[2] G. Vitagliano et al., arXiv:2104.05663 (2021)

Q 67: Optomechanics III

Time: Friday 11:00–13:00 Location: F442

Q 67.1 Fri 11:00 F442

Direct laser-written optomechanical membranes in fiber Fabry-Perot cavities — •Lukas Tenbrake[1], Alexander Fassbender[2], Sebastian Hofferberth[1], Stefan Linden[2], and Hannes Pfeifer[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Physics, University of Bonn, Germany

Cavity optomechanical experiments in micro- and nanophotonic systems have demonstrated record optomechanical coupling strenghts, but require elaborate techniques for interfacing. Their scaling towards larger systems including many mechanical and optical resonators is limited. Here, we demonstrate a directly fiber-coupled tunable and highly flexibile platform for cavity optomechanics based on 3D laser written polymer structures directly integrated into fiber Fabry-Perot cavities. Our experiments show vacuum coupling strengths of $\gtrsim 30\,\mathrm{kHz}$ at mechanical mode frequencies of $\gtrsim 3\,\mathrm{MHz}$. This allows us to optomechanically tune the mechanical resonance frequency by tens of kHz exceeding the mechanical linewidth at cryogenic temperatures of $\sim 6\,\mathrm{kHz}$ at $4\,\mathrm{K}$. The ease of interfacing the system through the direct fiber coupling, its scaling capabilities to larger systems with coupled resonators, and the possible integration of electrodes makes it a promising platform for upcoming challenges in cavity optomechanics. Fiber-tip integrated accelerometers, directly fiber coupled systems for μ-wave to optics conversion or large systems of coupled mechanical resonators are in reach.

Q 67.2 Fri 11:15 F442

Hollow core photonic crystal fibers as sources for levitated nanoparticles in future quantum experiments — •Stefan Lindner, Yaakov Fein, Paul Juschitz, Jakob Rieser, Markus Aspelmeyer, and Nikolai Kiesel — University of Vienna, Faculty of Physics

Over the last decade several proposals using optically levitated nanoparticles as a platform to create macroscopic quantum states have been put forth. Yet as of today environmental decoherence still poses a substantial roadblock hindering the access to such experiments. Especially the interaction with background gas molecules has to be overcome by reducing the pressure these experiments are conducted in. The attainable vacuum for levitation experiments is directly related to the type of particle loading scheme in place. Here we present a novel method for loading nanoparticles via hollow core photonic crystal fibers, that allows direct loading of into pressures in the ultra high vacuum (UHV) regime.

By guiding two counter-propagating lasers of equal wavelength through a hollow core fiber one creates an "optical conveyor belt" that connects an UHV pressure main vacuum chamber to an ambient or low vacuum "loading" chamber. By detuning one of the two lasers with respect to the other, nanoparticles can be transported from the loading chamber, through the fiber, directly into the trap in the main vacuum chamber. This handover of particles has been demonstrated down to pressures of 10^{-8} mbar and is currently extended, targeting below 10^{-10} mbar, where gas collisions occur at sub-kHz timescales.

Q 67.3 Fri 11:30 F442

Tunable light-induced dipole-dipole interaction between optically levitated nanoparticles — •Jakob Rieser[1], Mario A. Ciampini[1], Henning Rudolph[2], Nikolai Kiesel[1], Klaus Hornberger[2], Benjamin A. Stickler[2], and Uroš Delić[1] — [1]Faculty of Physics, University of Vienna, Vienna, AUT — [2]Faculty of Physics, University of Duisburg-Essen, Duisburg, DEU

By coupling mechanical systems one can observe interesting collective effects, such as topological phonon transport or in the quantum case the possibility of entanglement. Current optomechanical experiments utilize an optical cavity mode to mediate interactions, which limits the tunability of the system. Here we are interested in directly coupling parties using scattered light in a finely controlled manner.

It has been known that optically levitated microparticles can interact through light – optically bind – and form self-organized patterns that resemble crystals. In my talk, I will present coherent, direct interaction between two dielectric nanoparticles levitated in a trap array. In contrast to previous optical binding studies, the interparticle coupling is inherently non-reciprocal. I will show how tuning the relative optical phase, laser powers, and the particle distance gives us full control of the optical interactions. Finally, I will demonstrate how we can suppress the optical coupling using the light polarization, in which case we can observe electrostatic interactions.

Q 67.4 Fri 11:45 F442

Co-trapping an atomic ion and a silica nanoparticle in a Paul trap — •Dmitry S. Bykov, Lorenzo Dania, Florian Goschin, and Tracy E. Northup — Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria

In this work, we experimentally demonstrate the simultaneous trapping of two objects whose charge-to-mass ratio differs by six orders of magnitude in the same Paul trap. The first object is a calcium ion with a single elementary charge and a mass of 40 Da. The second object is a silica nanoparticle with 1000 elementary charges and a mass of 10^{10} Da. To achieve simultaneous trapping, we drive the trap electrodes with two radio-frequency tones: one to trap the nanoparticle and the other to trap the atomic ion. Such a dual-frequency drive allows us to circumvent the charge-to-mass selectivity of a Paul trap. This demonstration paves the way for building a hybrid ion-nanoparticle system under ultra-high vacuum. Such a system is a promising platform for advancing quantum control of particle motion and testing quantum mechanics at unprecedented levels.

Q 67.5 Fri 12:00 F442

Optomechanics with a torsional mode of an optical nanofiber — •Jihao Jia, Sebastian Pucher, Arno Rauschenbeutel, Philipp Schneeweiss, Felix Tebbenjohanns, and Jürgen Volz — Humboldt-Universität zu Berlin, Germany

Tapered optical fibers (TOFs) with a sub-wavelength-diameter waist, so-called optical nanofibers, have proven to be extremely versatile tools with applications ranging from telecommunication devices and sensors to trapping and optically interfacing laser-cooled atoms. Surprisingly, in the realm of optomechanics, the mechanical motion of the nanofiber waist of such TOFs is so far largely unexplored. Here we show experimentally that the torsional motion of the nanofiber waist of a TOF can be extremely well decoupled from the environment, reaching quality factors of up to 10 million. By analyzing the polarization fluctuations of a probe light field transmitted through the TOF, we measure the nanofiber's torsional motion in real time. Feeding back this signal to the nanofiber, we cool its fundamental torsional mode by several orders of magnitude to sub-Kelvin temperatures. Based on our observations, we discuss the prospects of ground-state cooling. Our results show that optical nanofibers represent a competitive optomechanical platform, which may enable new hybrid quantum systems, e.g., by coupling the torsional motion to cold atoms that are trapped in the evanescent field surrounding the nanofiber.

Q 67.6 Fri 12:15 F442

Strong Coulomb interaction between highly charged optically trapped sub-micron particles in vacuum — •Ayub Khodaee[1], Anton Zasedatelev[1], and Markus Aspelmeyer[1,2] — [1]Faculty of Physics, Boltzmanngasse 5, 1090 Wien, Vienna, Austria — [2]IQOQI - Vienna, Boltzmanngasse 3, 1090 Wien, Vienna, Austria

Optically levitated nano- and micro-particles, in which the motion of a mechanical degree of freedom is controlled via light-induced forces, comprise a new class of ultimately isolated macroscopic mechanical oscillators with high-quality factors exceeding 108 [Gonzalez-Ballestero, C., et al., Science 374.6564 (2021): eabg3027]. One of the central goals of levitated optomechanics nowadays is to prepare a particle wave packet in a sufficiently pure quantum state and generate entanglement between macroscopic mechanical oscillators [Gonzalez-Ballestero, C., et al., Science 374.6564 (2021): eabg3027]. Strong electrostatic interaction between highly charged levitated particles is one the most promising strategies to generate stationary entangled states. The preparation of a pair of highly charged optically levitated particles in the ultra-high vacuum (UHV) is an experimental challenge on the way to implement ground state cooling and quantum entanglement between optically trapped particles. Here we address this problem and present our experimental approach to load, charge, and control sub-micron particles in tunable optical traps in UHV.

Q 67.7 Fri 12:30 F442

Numerical analysis of a novel optical trap design based on optomechanical backactions — •Jose Manuel Monterrosas Romero[1,2], Ester Koistinen[1], Seyed Khalil Alavi[1,2], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universität Stuttgart, 70569 Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, 70569 Stuttgart, Germany

Optical traps have proven to be an invaluable tool for many scientific applications. However, due to the nature of the traps, their spatial shapes are diffraction limited, and a trapped object often suffers from severe absorption heating, especially in a high vacuum. To mitigate these issues, we propose a new type of optical trap based on the use of dynamic optomechanical backactions between optical nanocavities and a dielectric particle. Our trap consists of two photonic crystal nanobeam cavities (PCNC) closely placed in parallel. Numerical simulations confirm that an extremely sharp potential can be created in the middle between the two PCNCs, which can trap a dielectric nanoparticle stably at room temperature. Furthermore, we find that the dynamic optomechanical forces allow for trapping the particle with significantly suppressed optical heating, therefore reducing heat-induced trap instability. We also present the possibility of creating more complex trapping potentials by adding a second beam with different frequencies for each cavity. All of these unique properties make our system a promising trapping platform for levitated optomechanics.

Q 67.8 Fri 12:45 F442

On a way to quantum entanglement via Coulomb interaction between optically trapped macroscopic particles — •Anton Zasedatelev[1], Ayub Khodaee[1], Klemens Winkler[1], and Markus Aspelmeyer[1,2] — [1]University of Vienna — [2]The Institute for Quantum Optics and Quantum Information

The quantum superposition principle and entanglement are one of the most striking features of the microscopic world and the key resource behind emerging quantum technologies, including quantum telecommunication, computing, metrology etc. The quantum entanglement of macroscopic mechanical oscillators is a unique resource to examine fundamental principles of quantum mechanics at the interface with classical physics. Electromagnetically induced quantum entanglement of macroscopic objects is essential for understanding the role of electromagnetic radiation quantization and vacuum fluctuations in ensuring consistency of the macroscopic systems to the basic principles of quantum mechanics, e.g. causality and complementarity. Here we discuss experimental challenges towards generation of quantum entanglement between center-of-mass motions of two highly charged sub-micrometer dielectric particles optically levitated in an ultra-high vacuum. This work is in progress, and takes the following steps: (i) optical trapping of two closely located and highly charged particles (ii) ground state cooling of their mechanical normal modes, (iii) generation and measurement of entanglement through long-range Coulomb interaction.

Q 68: Quantum Gases: Bosons V

Time: Friday 14:30–16:15 Location: B305

Q 68.1 Fri 14:30 B305

Integrating physical intuition into neural networks for potential reconstruction in ultracold atoms — •Miriam Büttner and Axel U. J. Lode — Institute of Physics, Albert-Ludwig University of Freiburg, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany

Ever since the rise of interest in Bose-Einstein Condesates (BECs), the research field of interacting ultracold indistinguishable particles has expanded, both in its experimental realizations as well as in its theoretical descriptions.In this work, we present a physically motivated neural network architecture for the extraction of quantum observables from single-shot measurements of ultracold atoms. The focus of the work is put on the inclusion of physical intuition into such a network architecture. Our proposed architecture utilizes extended pre-processing that exploits the stochastic nature of the measurement results, given that the so called single-shot images consist of samples of the N-body density. As we are extracting an external potential from samples of a density, our loss function takes inspiration from the constrained-search approach to density functional theory. We thus demonstrate, that in a way similar to inverse density functional methods, a Bose-Einstein condensate*s external potential can be reconstructed.

Q 68.2 Fri 14:45 B305

An unsupervised deep learning algorithm for single-site reconstruction in quantum gas microscopes with short-spaced optical lattices — •Alexander Impertro[1,2], Julian Wienand[1,2], Sophie Häfele[1,2], Hendrik von Raven[1,2], Scott Hubele[1,2], Till Klostermann[1,2], Cesar Cabrera[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]Department of Physics, LMU München, and MCQST, 80799 Munich — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching

In quantum gas microscopy experiments, reconstructing the site-resolved lattice occupation with high fidelity is essential for the accurate extraction of physical observables. For short interatomic separations and limited signal-to-noise ratio, this task becomes exponentially more challenging. Previous methods use only limited a-priori knowledge about the system at hand and rapidly decline in performance as the lattice spacing is decreased below the imaging resolution. Here, we present a novel algorithm based on deep convolutional neural networks to reconstruct the site-resolved lattice occupation in a regime, where the lattice constant is half the imaging resolution, with high fidelity. The network can be directly trained with experimental fluorescence images in an unsupervised manner. It is able to capture density-dependent effects due to its inherent nonlinearity and allows a fast reconstruction of large images. Additionally, we demonstrate two methods to benchmark the experimental reconstruction fidelity with data from our cesium quantum gas microscope, where we find promising results across all fillings.

Q 68.3 Fri 15:00 B305

Spectroscopy of xenon-helium mixtures for Bose-Einstein condensation of vacuum-ultraviolet photons — •Thilo vom Hövel, Eric Boltersdorf, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Bose-Einstein condensation of visible spectral range photons is currently investigated in our and other groups using liquid dye solutions as thermalization media for photon gases in optical microcavities. We here propose an experimental approach to apply these principles for the construction of a coherent light source in the VUV (100 - 200nm), a wavelength regime for which it is difficult to construct lasers due to the high pump power needed to achieve population inversion in active media.

As dye solutions are not suitable for VUV operation, an alternative thermalization medium needs to be found, allowing for contact to the thermal environment by repeated absorption and re-emission of photons. Our candidate are dense heteronuclear xenon-helium mixtures with absorption and emission features around 147nm wavelength, provided by quasi-molecular states formed from the atomic xenon's $5p^6$ and $5p^5 6s$ states, respectively. We here report on recent spectroscopic investigations of such samples at high pressure, with particular emphasis on the spectral overlap between absorption and emission profiles. Further, results on the validity of the thermodynamic Kennard-Stepanov relation are presented, whose fulfillment is a prerequisite for the proposed approach.

Q 68.4 Fri 15:15 B305

How creating one additional well can generate Bose–Einstein condensation — •Mihály Máté[1,5], Örs Legeza[1], Rolf Schilling[2], Mason Yousif[3], and Christian Schilling[3,4] — [1]Wigner Research Centre for Physics, Budapest, Hungary — [2]Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany — [3]Clarendon Laboratory, University of Oxford, Oxford, United Kingdom — [4]Department of Physics, Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität, München, Germany — [5]Department of Mathematics, Technical University of Munich, Germany

We propose and study a model for N hard-core bosons which allows for the interpolation between one- and high-dimensional behavior by variation of just a single external control parameter s/t. It consists of a ring-lattice of d sites with a hopping rate t and an extra site at its center. Increasing the hopping rate s between the central site and the ring sites induces a transition from the regime with a quasi-condensed number N_0 of bosons proportional to $\sqrt{N}$ to complete condensation with $N_0 \simeq N$. In the limit $s/t \to 0, d \to \infty$ the low-lying excitations follow from an effective ring-Hamiltonian. An excitation gap makes the condensate robust against thermal fluctuations at low temperatures. These findings are supported and extended by large scale density matrix renormalization group computations. We show that ultracold bosonic atoms in a Mexican-hat-like potential represent an experimental realization allowing one to observe the transition from quasi to complete condensation by creating a well at the hat's center.

Q 68.5 Fri 15:30 B305

Wilsonian Renormalization in the Symmetry-Broken Polar Phase of a Spin-1 Bose Gas — •Niklas Rasch[1], Aleksandr N. Mikheev[1,2], and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, Germany

Wilsonian renormalization group theory is applied in a 1-loop perturbative expansion to the spin-1 Bose gas both in the thermal and in the symmetry-broken polar phase. For the latter, the symmetry is broken explicitly and flow equations including the renormalization of the condensate density are computed. A scheme is established for investigating the flow equations in a cut-off independent manner at fixed particle density. We observe the emergence of anomalous scaling in the chemical potential which relates to a flow towards the quasi-relativistic phononic regime. To restore convergent flow equations, we explicitly include wave-function renormalization of the first order time derivative and adapt the rescaling scheme. This yields convergent, cut-off independent predictions for all couplings. We are able to qualitatively describe the gas close to criticality, e.g. the shift of the critical temperature, and quantitatively predict low-temperature observables, e.g. condensate depletion.

Q 68.6 Fri 15:45 B305

Quantum walk of two composite bosons — •Pedro Weiler, Mama Kabir Njoya Mforifoum, Gabriel Dufour, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg i.Br.

Many-body interference plays a key role in the dynamics of identical particles. In this contribution we discuss the quantum walk of two identical composite bosons on a 1D lattice. We consider composites made up of either two fermions or two bosons bound by contact interactions. Depending on the quantum statistics of the composite bosons' constituents, we observe different dynamical behaviours arising from an interplay of interaction and exchange processes.

Q 68.7 Fri 16:00 B305

Pairing of 2D electromagnetic bosons under spin-orbit coupling and transverse magnetic field — •Sergueï Andreev — Albert-Ludwigs-Universität Freiburg, D-79104 Freiburg

Exciton-polaritons in 2D semiconductors are electromagnetic bosons characterized by massive dispersion, polarization (spin) and pairwise interactions produced by the Coulomb forces between the constituent electrons and holes. Two bosons with opposite spins may form a bound state (biexciton). The bosons experience effective momentum-dependent magnetic fields due to the electron-hole exchange interaction and longitudinal-transverse splitting of the photon modes. These effective fields couple the spin-singlet biexciton to the continua in the triplet scattering channels. In this talk we shall discuss the ensuing phenomena for monolayer and bilayer semiconductors placed into an external transverse magnetic field (Faraday geometry). We predict biexcitonic halos possessing synthetic angular momenta $L_z = \pm 2\hbar$ [1] and dissociation of a biexciton Bose-Einstein condensate into a superfluid current of excitons upon increasing the density. We point out affinity of these phenomena to the polarized exciton superstripe emerging at zero transverse magnetic field in the equilibrium many-body phase diagram of dipolar excitons in bilayers at sufficiently large inter-layer distances, where the biexciton becomes weakly bound [2].

References:

[1] S. V. Andreev, Phys. Rev. B 106, 155157 (2022)
[2] S. V. Andreev, Phys. Rev. B 103, 184503 (2021)

Q 69: Ultra-cold Atoms, Ions and BEC V (joint session A/Q)

Time: Friday 14:30–16:30 Location: F303

Invited Talk Q 69.1 Fri 14:30 F303

Observation of vibrational dynamics in an ion-Rydberg molecule by a high-resolution ion microscope — •Moritz Berngruber[1], Viraatt Anasuri[1], Yiquan Zou[1], Nicolas Zuber[1], Óscar Andrey Herrera Sancho[1,2], Ruven Conrad[1], Florian Meinert[1], Robert Löw[1], and Tilman Pfau[1] — [1]Universität Stuttgart — [2]Escuela de Física, Universidad de Costa Rica, San José

Vibrational dynamics in conventional molecules takes usually place on a timescale of picoseconds or shorter, therefore it is hard to observe. In this talk, we report on a direct spatial observation of vibrational dynamics in an ion-Rydberg atom molecule where the vibrational dynamics happens on much slower timescales and can therefore be directly studied.

Highly excited Rydberg atoms can form quite unusual bonds, which lead to long-range Rydberg molecules with exotic properties, here we study a molecular ion that is formed due to the interaction between an ionic charge and a flipping-induced dipole of a Rydberg atom. Due to the large bond length of the molecule, dynamical processes are slowed down drastically leading to vibrational dynamics in the microsecond regime that can be observed in real space by using a high-resolution ion microscope. By applying a weak external electric field of a few mV/cm, it is possible to control the orientation of the ionic ultralong-range Rydberg molecules directly during the creation process. When the field is quenched off in a subsequent step, the vibrational dynamics can be initialized and observed under the ion microscope in real space.

Q 69.2 Fri 15:00 F303

Dynamics of a driven atomic Josephson junction — •Vijay Singh[1], Ludwig Mathey[2], and Luigi Amico[1] — [1]Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE — [2]Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany

Using classical-field simulations we study the dynamics of a Josephson junction created by separating two two-dimensional atomic clouds with a tunneling barrier. We explore various condensate geometries, as well as different barrier protocols. This allows us to characterize the DC to AC Josephson effect, which we compare with the prediction of the two-coupled equations. Furthermore, we consider a periodic driving of the barrier protocol to study the driving effect on the voltage-current characteristic, resulting in reminiscent Shapiro steps. We discuss these dynamical behaviors in both underdamped and overdamped regimes and describe them using the two-coupled equations.

Q 69.3 Fri 15:15 F303

Quantum simulations with circular Rydberg atoms — •Christian Hölzl, Aaron Götzelmann, Moritz Wirth, and Florian Meinert — 5th Institute of Physics, Universität Stuttgart,

Stuttgart, Germany

Highly excited low-L Rydberg atoms in configurable mircotrap arrayshave recently proven highly versatile for exploring quantum many-body systems with single particle control. We aim to increase the coherence time of the Rydberg platform by using high-L circular Rydberg states, which promise orders of magnitude longer lifetimes compared to their low-l counterparts. I will report on the status of a new experimental apparatus for realizing arrays of trapped and long-lived circular Rydberg atoms at room temperature. To this end, we have prepared single Strontium atoms inside a suppression capacitor made from indium tin oxide (ITO). The capacitor is designed to stabilize the circular Rydberg atoms against detrimental black-body radiation, while keeping excellent high-NA optical access for visible light. I will report on our progress to laser-excite Rydberg singlet F-states via a three-photon scheme. The latter serve as a suitable starting point for accessing circular Rydberg states via adiabatic state transfer.

Q 69.4 Fri 15:30 F303

Time-resolved meausrements of the anomalous Hall velocity — •Alexander Ilin, Klaus Sengstock, and Juliette Simonet — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

The anomalous velocity is a purely intrinsic interference effect that gives rise to many fascinating transport phenomena in solids, including the anomalous Hall effect (AHE), the spin Hall effect (SHE), and their quantized versions. However, measuring the anomalous velocity in real solid-state materials is challenging as a direct observation of electron wave-packet dynamics is usually impeded by inherent short times for scattering.

Here, we report on direct measurements of the anomalous velocity for condensates in an accelerated optical boron-nitride lattice. By tracing the coherent evolution of Bloch states in momentum space, we can precisely extract the time-dependent anomalous velocity along different paths in reciprocal space and infer the associated local Berry curvature. Using this method, we demonstrate geometric pumping and a bosonic counterpart of the valley Hall effect for condensates in the second Bloch band, where atoms in different valleys experience a net anomalous transport into opposite direction.

Q 69.5 Fri 15:45 F303

Tuneable Long-range Interaction by Coupling Opposite Parity Rydberg States — •Philip Osterholz, Lea Steinert, Arno Trautmann, Ludwig Müller, Roxana Wedowski, and Christian Gross — Physikalisches Institut, Eberhard Karls Universität Tübingen, 72076 Tübingen, Germany

Rydberg atoms in optical tweezers have proven to be a major working horse in studying long-range interacting systems. The tunability of the interaction allows for exploring large regions of phase diagrams and novel physics in various experimental settings. Here, we present how the dipolar coupling between opposite parity rydberg states can extend the interaction range in current rydberg tweezer experiments. This paves the way for studying quantum spin systems with an enriched variety of interactions in state-of-the-art quantum simulators.

Q 69.6 Fri 16:00 F303

Tailoring the Phonon Environment of Embedded Rydberg Aggregates — •Sidharth Rammohan[1], Alexander Eisfeld[2], and Sebastian Wüster[1] — [1]IISER Bhopal, Madhya Pradesh, India. — [2]MPIPKS, Dresden, Germany.

State-of-the-art experiments can controllably create Rydberg atoms inside a Bose-Einstein condensate (BEC) [1], where the electron-atom interactions can be tuned making the hybrid system suitable for quantum simulation. In our work we study the dynamics of a single or multiple Rydberg atoms embedded inside a BEC, to assess their utility for controlled studies of excitation transport. For this, we first develop a theoretical framework to calculate the input parameters like the bath correlation function, initially for a single Rydberg atom, possibly in two internal states in a BEC [2]. The electron-atom contact interactions lead to Rydberg-BEC coupling, which creates phonons in the BEC. Using the spin-boson model with the calculated parameters, we examine the decoherence dynamics of a Rydberg atom in a superposition of the states, resulting from the interaction with its condensate environment and also study the emergence of Non-Markovian features in the system [3]. The scenario with a single Rydberg atom is then extended to the aggregate case, where one of the atoms in the aggregate is in the p state, while the rest are in the s state, allowing us to set up dynamics similar to those found in light-harvesting complexes. References: [1] J. B. Balewski, et.al,. Nature 502 664 (2013). [2] S. Rammohan, et.al,. Phys. Rev. A 103, 063307 (2021). [3] S. Rammohan, et.al,. Phys. Rev. A 104, L060202 (2021).

Q 69.7 Fri 16:15 F303

Sympathetic cooling of charged particles in separate Penning traps via image currents — •Hüseyin Yildiz[1], Peter Micke[2,3], Markus Wiesinger[2], Christian Will[2], Fatma Abbass[1], Stefan Erlewein[2,4], Julia Jäger[2,4,5], Barbara Latacz[4], Andreas Mooser[2], Daniel Popper[1], Gilbertas Umbrazunas[4,6], Elise Wursten[4], Klaus Blaum[2], Christian Ospelkaus[5,7], Wolfgang Quint[8], Jochen Walz[1,9], Christian Smorra[1,4], and Stefan Ulmer[4,10] — [1]Johannes Gutenberg-Universität Mainz — [2]Max-Planck-Institut für Kernphysik — [3]CERN — [4]RIKEN — [5]Physikalisch-Technische Bundesanstalt — [6]Eidgenössisch Technische Hochschule Zürich — [7]Leibniz Universität Hannover — [8]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [9]Helmholtz-Institut Mainz — [10]Heinrich-Heine-Universität Düsseldorf

Cooling of trapped charged particles to the mK range or even below is crucial in many precision experiments, but can be a challenge when suitable laser transitions are missing. We recently demonstrated a new sympathetic cooling method to cool a single proton via image currents of a laser-cooled Be^+ cloud located in a separate trap. This concept is promising, because it is not limited to small distances and is generally scalable. In particular, any kind of charged particles can be cooled, including antimatter and highly charged ions.

This talk summarizes our previous work and reports about our recent progress towards an advanced coupling scheme based on a detuned LC-circuit.

Q 70: Precision Measurements: Atom Interferometry II (joint session Q/A)

Time: Friday 14:30–16:30 Location: F342

Q 70.1 Fri 14:30 F342

INTENTAS - Interferometry with entangled atoms in space — •Jan Simon Haase[1], Janina Hamann[1], Jens Kruse[2], and Carsten Klempt[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstr. 30b, 30167 Hannover

Atom interferometers are high-precision measurement devices for the sensing of inertial moments as accelerations and rotations. A zero-gravity environment enables prolonged interrogation time and consequently a higher resolution. Therefore, space-borne atom interferometers promise unprecedented resolution for a wide range of applications from geodesy to fundamental tests.
A fundamental limit for their precision is the Standard Quantum Limit (SQL), which determines a limit for the interferometric resolution. The SQL can only be surpassed by using entangled ensembles of atoms as a source for the interferometer.
The goal of the INTENTAS project (Interferometry with entangled atoms in space), which will be presented in this talk, is to demonstrate a compact source of entangled atoms in the Einstein-Elevator, a microgravity platform which allows zero-gravity tests for up to 4 s. The planned experiments will pave the way to employ entangled atomic sources for high-precision interferometry in space applications.

Q 70.2 Fri 14:45 F342

Generalized Ramsey Protocols — •Maja Scharnagl — Institute for theoretical physics, Leibniz University Hannover, Germany

We consider a variational class of generalized Ramsey protocols with two one-axis-twisting (OAT) operations, one before and one after the phase imprint, for which we optimize the direction of the signal imprint, the direction of the second OAT interaction and the measurement direction via a numerical routine for global optimization of constrained parameters. In doing so, we distinguish between protocols whose signal from spin projection measurements exhibits a symmetric or antisymmetric dependence on the phase to be measured. We find that the Quantum Fisher Information, which bounds the sensitivity achievable with a one-axis-twisted input state, can be saturated in our variational class of protocols for nearly all initial squeezing strengths. Therefore, the generalized Ramsey protocols considered here allow us to reduce quantum projection noise in comparison to the standard Ramsey protocol considerably.

Q 70.3 Fri 15:00 F342

Dynamics of quantum gases mixtures in space experiments — •Annie Pichery[1,2], Matthias Meister[3], Eric Charron[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, France — [3]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany

Ultra-cold atomic ensembles are a prime choice for sources in quantum sensing experiments. Space provides an environment where these clouds can float for extended times of several seconds, thus boosting the precision of these sensors. It also enables the operation of Bose-Einstein Condensate (BEC) mixtures for dual interferometers in miscibility conditions not possible on ground.

Simulating such dynamics of interacting dual species BEC mixtures presents however computational challenges due to the long expansion times. In this contribution, scaling techniques to overcome these limits are presented and illustrated in the case of space experiments on the ISS and aboard sounding rockets.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. CAL-II 50WM2245A/B.

Q 70.4 Fri 15:15 F342

Atom interferometry on the International Space Station — •Matthias Meister[1], Naceur Gaaloul[2], Nicholas P. Bigelow[3], and the CUAS team[1,2,3,4] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Leibniz University Hannover, Institute of Quantum Optics, QUESTLeibniz Research School, Hanover, Germany — [3]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA — [4]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQST, Ulm University, Ulm, Germany

Matter-wave interferometers based on Bose-Einstein condensates are exquisite tools for precision measurements, relativistic geodesy, and Earth observation. Employing this quantum technology in space further increases the sensitivity of the measurements due to the extended free fall times enabled by microgravity. Here we report on a series of experiments performed with NASA's Cold Atom Lab aboard the ISS demonstrating atom interferometers with different geometries in orbit. By comparing measurements with atoms in magnetic sensitive and insensitive states we have realized atomic magnetometers mapping the residual magnetic background in the apparatus. Our results pave the way towards future quantum sensing missions with cold atoms in space.

This work is supported by NASA/JPL through RSA No. 1616833 and the DLR Space Administration with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers 50WM1861-2 and 50WM2245-A/B.

Q 70.5 Fri 15:30 F342

Large-momentum-transfer atom interferometers with μrad-accuracy using Bragg diffraction — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], Christian Schubert[2,3], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik

Large-momentum-transfer atom interferometers that employ elastic Bragg scattering from light waves are among the most precise quantum sensors available. To increase their accuracy from the mrad to the μrad regime, it is necessary to understand the rich phenomenology of Bragg interferometers, which can be quite different from that of a standard two-mode interferometer. We develop an analytic model for the interferometer signal and demonstrate its accuracy using extensive numerical simulations. Our analytic treatment enables the determination of the atomic projection noise limit of an LMT Bragg interferometer and provides the means to saturate this limit. It allows suppression of systematic phase errors by two orders of magnitude down to a few μrad using appropriate pulse parameters.

This work is supported through the DFG via QuantumFrontiers (EXC 2123), and DQ-mat (CRC1227) within Projects No. A05, No. B07, and No. B09.

Q 70.6 Fri 15:45 F342

Applications of tuneable interactions in atom interferometry sources — •Alexander Herbst, Henning Albers, Wei Liu, Knut Stolzenberg, Sebastian Bode, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Atom interferometers are powerful tools for precision measurements in fundamental physics or applications such as inertial sensing. Fundamentally, the sensitivity of these devices is limited by shot noise, thus motivating high-flux atomic sources. Furthermore, control over the ensemble's initial conditions and its expansion dynamics is key for systematic error mitigation.

To address these challenges we demonstrate a high flux source of ultra-cold ^{39}K with nearly Heisenberg limited expansion rates in the horizontal plane. Due to its broad Feshbach resonances at comparably low magnetic fields ^{39}K allows for changing its atomic interactions without the need for complex coil setups. By dynamically tuning its scattering length along the evaporation trajectory we achieve quantum degeneracy in below 200 ms evaporation time, maintaining a constant flux. Subsequently, changing the scattering length to a minimal positive value reduces the mean-field energy, thus offering a simple and robust way to decrease the expansion rate to an effective temperature equivalent of a few nanokelvin. Moreover, our method can also be applied to improve more complex techniques such as matter-wave lensing, allowing for effective temperatures in the sub-nK regime.

Q 70.7 Fri 16:00 F342

Optical simulations for highly sensitive atom interferometry — •Gabriel Müller, Stefan Seckmeyer, and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Using atom interferometers as highly sensitive quantum sensors requires both precise understanding and control of their main building block: atom light interactions. To properly describe the atom light interactions we need an accurate description of the laser-driven light fields. Distortions of ideal Gaussian beams on their path to the atoms can cause several disturbing effects. For example, the occurrence of asymmetric optical dipole forces acting on the atoms can cause a loss of contrast. Here, we build an optical simulation tool using Fast-Fourier-transform beam propagation methods to take into account arbitrarily shaped obstacles. We compare these results, on small scales, to solutions of Maxwell's equations finding good agreement. Finally, we apply our optical simulations to guide the design of the next unit of NASA's Earth-orbiting Cold Atom Lab and DESIRE, a microgravity experiment searching for Dark Energy.

This work is supported by DLR funds from the BMWi (50WM2245A-CAL-II and 50WM2253A-(AI)^2).

Q 70.8 Fri 16:15 F342

BEC atom interferometry techniques for very long baselines — •Dorothee Tell[1], Vishu Gupta[1], Henning Albers[1], Klaus H. Zipfel[1], Christian Schubert[1,2], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]German Aerospace Center (DLR), Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

The Very Long Baseline Atom Interferometry (VLBAI) facility at the university of Hannover aims for high precision measurements of inertial quantities. Goals span from absolute gravimetry to fundamental physics at the interface between quantum mechanics and general relativity. To this end, the VLBAI facility will make use of ultracold atoms freely falling in a 10 m long vacuum tube with well-known bias forces. We will utilize Bragg atom optics to realize Mach-Zehnder-like geometries sensitive to acceleration.

Here we present the source of rubidium Bose-Einstein condensates ready to be installed at the bottom of the VLBAI baseline for interferometry on fountain trajectories. We demonstrate the necessary methods and schemes, such as matter-wave lenses, Bragg beam splitters and Bloch oscillations, in proof-of-principle experiments performed in the cm-scale baseline available in the source chamber. We discuss prospects and challenges of extending the free fall distance to 10 m.

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Q 71: Quantum Optics: Cavity and Waveguide QED III

Time: Friday 14:30–15:30 Location: F442

Q 71.1 Fri 14:30 F442

Waveguide QED with Mössbauer Nuclei — •Petar Andrejic[1], Leon Merten Lohse[2,3], and Adriana Palffy[4] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Deutsches Elektronen-Synchrotron — [3]Georg-August-Universität Göttingen — [4]Julius-Maximilians-Universität Würzburg

Grazing incidence X-ray waveguides have become a well established platform for X-ray quantum optics. In these systems the waveguide mediated collective coupling of the X-rays plays a significant role. Recently a formalism has been developed to describe the collective nuclear response using the classical electromagnetic Green's function for the waveguide [1,2]. However, so far these works have considered only translationally symmetric systems, and plane wave driving fields. We show that driving the waveguides at forward incidence instead allows for direct excitation of multiple guided modes, with centimetre scale attenuation lengths. In this regime, micro-patches of embedded Mössbauer nuclei absorb and emit collectively into a super-position of these modes, with the resultant radiation field displaying pronounced interference beats on a micrometre scale. By considering variations in the size and positions of the micro-patches, it is feasible to engineer the resultant inter-nuclear coupling, with potential for applications in quantum simulation and experimental exploration of mesoscopic quantum dynamics.

[1] X. Kong, D. E. Chang, and A. Pálffy, Phys. Rev. A 102, 033710 (2020)

[2] P. Andrejić and A. Pálffy, Phys. Rev. A 104, 033702 (2021)

Q 71.2 Fri 14:45 F442

Quantum State Preparation in a Micromaser — •Andreas J C Woitzik[1], Edoardo Carnio[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany

Quantum algorithms process information encoded into quantum states via an appropriate unitary transformation. Their purpose is to deliver a sought-after target state that represents the solution of a predefined computational problem. From a physical perspective, this process can be interpreted as a quantum state control problem, where a given target state is to be prepared with an optimally tailored unitary transformation. In this talk we adopt the one-atom (or micro-) maser, i.e., a string of atoms interacting sequentially with a cavity mode, to study the transfer of quantum information in state space. We aim, in particular, for the relation between the cavity's convergence towards a given target state and the entanglement content of the injected atomic string.

Q 71.3 Fri 15:00 F442

Star-to-chain transformations for ultra-strong coupling — David D. Noachtar[1], Johannes Knörzer[1,2], and •Robert H. Jonsson[1,3] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Institute for Theoretical Studies, ETH Zurich, Switzerland — [3]Nordita, Stockholm, Sweden

The ultra-strong coupling regime requires non-perturbative methods, for example, to calculate the radiation emitted from an atom. We show how star-to-chain transformations can be combined with methods based on matrix product state or Gaussian methods, respectively. Being well known in the study of open quantum systems, we demonstrate that the approach allows us to also treat field observables - both in vacuum states and thermal states of the field. As applications we consider giant atoms in the ultra-strong coupling regime [1], and the emission from a uniformly accelerated emitter in the Unruh effect [2].

[1] D. D. Noachtar, J. Knörzer, and R. H. Jonsson, "Nonperturbative treatment of giant atoms using chain transformations", Phys. Rev. A 013702, (2022).

[2] R. H. Jonsson, and J. Knörzer, "Star-to-chain transformations for relativistic matter-light interaction", in preparation.

Q 71.4 Fri 15:15 F442

Few-mode theory beyond the rotating-wave approximation — •Felix Riesterer, Lucas Weitzel, Dominik Lentrodt, and Andreas Buchleitner — Institute of Physics Albert-Ludwigs University of Freiburg Hermann-Herder-Str. 3 D-79104 Freiburg

For ideal cavities, the quantization of the electromagnetic field is rather simple. In real cavities with finite losses, however, the mode spectrum of the resonator becomes continuous, which makes the mathematical treatment numerically expensive and only possible with advanced techniques. It is then desirable to obtain a simplified description of the continuum, to model the field and quantum dynamics in open cavities. To overcome this problem, one uses projections to an equivalent system which is analog to the Jaynes-Cummings model coupled to an external heat bath, which can then be treated with the Lindblad formalism. In this process, the so-called rotating wave approximation has to be applied, where counter-rotating terms are omitted. In this work, we consider a generalized system-bath model by adding the counter-rotating terms to the commonly considered Hamiltonian. Our approach is aimed at understanding how these models can be applied or generalized for complex resonators with large losses, as they are encountered, e.g., in plasmonic cavities.

Q 72: Precision Spectroscopy of Atoms and Ions V (joint session A/Q)

Time: Friday 14:30–16:00 Location: B302

Q 72.1 Fri 14:30 B302

Superconducting magnetic shielding for trapped ion qubits — •Elwin A. Dijck[1], Christian Warnecke[1,2], Claudia Volk[1], Stepan Kokh[1], Kostas Georgiou[1,3], Lakshmi P. Kozhiparambil Sajith[1,4,5], Christopher Mayo[1,3], Andrea Graf[1], José R. Crespo López-Urrutia[1], and Thomas Pfeifer[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Heidelberg University — [3]University of Birmingham, United Kingdom — [4]DESY, Zeuthen — [5]Humboldt University of Berlin

Merging a linear Paul trap with a superconducting RF resonator produces a trapping environment with minimal magnetic field noise, ideal for precision spectroscopy and (highly charged) ion qubits. We characterize our ion trap of this type built from niobium [1] using microwave spectroscopy of Be^+ hyperfine qubits, determining the magnetic field stability and shielding factor. Due to flux trapping, the magnetic field applied during cooldown remains present in the ion trap and no external field needs to be applied during subsequent trap operation at cryogenic temperature. We find the trapped magnetic field to be stable over a period of months with relative changes at the 10^{-10} s^{-1} level. Additionally, magnetic field noise, which often limits qubit coherence, is passively shielded by the superconductor at all frequencies down to DC. Using Ramsey interferometry and spin echo measurements, we find coherence times of >100 ms without active field stabilization.

[1] J. Stark et al., Rev. Sci. Instrum. **92**, 083203 (2021)

Q 72.2 Fri 14:45 B302

Progress toward direct frequency comb spectroscopy of

^{229m}**Th** — •Lars von der Wense[1], Chuankun Zhang[2], John F. Doyle[2], and Jun Ye[2] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]JILA, University of Colorado, Boulder, USA

Laser spectroscopy of the first excited nuclear state of ^{229}Th poses a long-standing challenge. Several groups worldwide are aiming for this goal, since success promises the development of a first nuclear optical clock of highest accuracy [1]. In this talk I will present the most recent progress of the efforts at JILA in Boulder, where direct frequency comb spectroscopy of ^{229m}Th is targeted [2]. For this purpose, a tunable VUV frequency comb has been developed [3] and new ^{229}Th targets were produced. Also, planned investigations within the new NuQuant project at MPQ will be addressed.

[1] L.v.d.Wense, B.Seiferle, Eur.Phys.J.A 56:277 (2020).
[2] L.v.d.Wense, C.Zhang, Eur.Phys.J.D 74:146 (2020).
[3] C. Zhang et al., Optics Letters 47, 5591 (2022).
Supported by NSF (PHY-1734006); NIST; ARO (W911NF2010182); AFOSR (FA9550-19-1-0148); Alexander von Humboldt Foundation; BMBF (13N16295).

Q 72.3 Fri 15:00 B302

BASE-STEP and the Permanent Magnet Trap — •Daniel Popper[1], Fatma Abbass[1], Hüseyin Yildiz[1], Markus Wiesinger[4], Christian Will[4], Björn-Benny Bauer[1,2], Jack Devlin[2,3], Stefan Erlewein[2,4], Julia Jäger[2,4,6], Barbara Latacz[2,3], Peter Micke[3,4], Elise Wursten[3], Gilbertas Umbrazunas[2,9], Klaus Blaum[4], Christian Ospelkaus[5,6], Wolfgang Quint[7], Jochen Walz[1,8], Stefan Ulmer[2,10], Christian Smorra[1], and Matthew Bohman[2,4] — [1]JGU Mainz, Germany — [2]Fundamental Symmetries Laboratory, RIKEN, Wako-shi, Japan — [3]CERN, Geneva, Switzerland — [4]MPI for Nuclear Physics, Heidelberg, Germany — [5]Leibniz Universität Hannover, Germany — [6]Physikalisch Technische Bundesanstalt, Braunschweig, Germany — [7]GSI, Darmstadt, Germany — [8]Helmholtz Intitute Mainz, Germany — [9]ETH Zürich, Switzerland — [10]Heinrich-Heine-Universität Düsseldorf, Germany

The ERC Project BASE-STEP is dedicated to the development of transportable antiproton traps to enhance the sensitivity of CPT invariance tests with antiprotons that are conducted in the BASE collaboration. For this, STEP uses a transportable superconducting magnet with a Penning trap system on a portable experiment frame. We have started commissioning the setup at CERN, and successfully tested our 90° defelctor at the end of 2022. In addition, we designed a permanent magnet set-up, consisting of two aubert- magnets that was conceived as an alternative to a superconducting magnet in the STEP concept that is more compact. Within the comissioning of the permanent magnet trap We succeeded in detecting He^{+} ions in EBIT operation.

Q 72.4 Fri 15:15 B302

Nuclear moments and isotope shifts of $^{249-253}$Cf probed by laser spectroscopy — •Dominik Studer for the Cf-Collaboration — Institut für Physik, JGU Mainz — GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — Helmholtz-Institut Mainz

Obtaining a comprehensive picture of nuclear phenomena in heavy nuclei requires precise measurements of, e.g., spins, electromagnetic moments and charge radii. These provide important data to pin down shell closures and to reveal their effect on observables, and serve as benchmarks for theory. However, experiments at the heavy-element frontier are challenging due to of limited sample sizes or production yields, and scarcity of atomic structure information. In this contribution we report on high-resolution laser spectroscopy of $^{249-253}$Cf across the $N = 152$ shell closure. A sample containing $^{249-252}$Cf was produced in the HFIR reactor at Oak Ridge National Laboratory, USA. Part of this sample was later re-irradiated at the high-flux reactor at ILL to obtain ≈20 fg of ^{253}Cf. The spectroscopic measurements were carried out at the RISIKO mass separator in Mainz. Spectrocopy with the laser perpendicular to the atomic beam using the PI-LIST ion source proved to be feasible with sample sizes on the femtogram level. Isotope shifts and hyperfine structures were measured for three ground-state transitions with linewidths in the order of 100 MHz, allowing the determination of the nuclear magnetic dipole moments of ^{249}Cf, ^{251}Cf and ^{253}Cf. The spectroscopic measurements are presented and the results are compared to state-of-the-art theoretical calculations.

Q 72.5 Fri 15:30 B302

Towards Coulomb coupling of a proton and a single ^{9}Be^{+} ion by using a microfabricated Penning trap — •Julia-Aileen Coenders[1], Jan Schaper[1], Juan Manuel Cornejo[1], Jacob Stupp[1], Amado Bautista-Salvador[2], Stefan Ulmer[3,4], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]PTB, Bundesallee 100, 38116 Braunschweig, Germany — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN, Wako, Saitama 351-0198, Japan — [4]HHU Düsseldorf, Universitässtraße 1, 40225 Düsseldorf, Germany

The BASE collaboration has allowed to measure the g-factor of single (anti-)protons stored in Penning traps with an unprecedented precision. At BASE Hannnover, we want to contribute to this goal by developing cooling and detection techniques based on the coupling of single (anti-)protons to single ^{9}Be^{+} ions that are laser cooled to their motional ground state.

For the planned coupling and sympathetic cooling of a proton with a laser cooled ^{9}Be^{+} ion, we need an asymmetric double well potential, due to the different masses of the particles. To generate this potential, a miniaturized trap geometry needs to be developed. Here we present the microfabrication steps that we applied to fused silica wafers to fabricate the cylindrical electrodes of our micro coupling Penning trap with an inner diameter of 0.8 mm and an axial length of 0.2 mm. In addition, we will show our latest results on adiabatic transport of single laser cooled ^{9}Be^{+} ions, as well as the current work on the coupling of two ^{9}Be^{+} ions in a macro coupling trap of 8 mm inner diameter.

Q 72.6 Fri 15:45 B302

Accurate isotope shift measurements in the D1 and D2 lines of Sr^{+} — •Julian Palmes, Phillip Imgram, Hendrik Bodnar, Kristian König, Patrick Müller, Imke Lopp, and Wilfried Nörtershäuser — Institut für Kernphysik, TU Darmstadt, Germany

Accurate measurements of different transition frequencies in multiple isotopes allow for the determination of the isotope shift and thus the calculation of the field shift ratio f, which is an important parameter to compare experimental results with state-of-the-art atomic structure calculations. After previous measurements of the corresponding lines in isotopes of the other alkaline-earth metals Ca^{+} and Ba^{+}, absolute frequency measurements of the stable Sr^{+} isotopes will be performed to be followed later by investigations of the $4d \rightarrow 5p$ transitions. Information on these transitions is required for an experiment on stable and short-lived Sr^{+} ions in a Paul trap, currently being prepared at the KU Leuven. We report on measurements of the D1 and D2 transitions, using the quasi-simultaneous collinear/anticollinear laser spectroscopy (CLS). These were carried out with the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA) at the Technical University of Darmstadt. Additionally, this method allowed for a precise observation of the hyperfine splitting of the ^{87}Sr^{+} isotope. Funding by BMBF under contract 05P21RDFN1 is acknowledged.