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

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Overview of Invited Talks and Sessions

(Lecture halls a310, e001, e214, f342, f435, and f442; Poster Empore Lichthof)

Invited Talks

Q 6.1	Mon	11:00–11:30	f342	**Hilbert space structure of eigenstates in many-body quantum systems** — •Alberto Rodríguez
Q 7.1	Mon	14:00–14:30	a310	**Phonon engineering and manipulation at the nanoscale** — •Ilaria Zardo
Q 9.1	Mon	14:00–14:30	e214	**Critical dynamics and prethermalization in lattice gauge theories** — •Jad Halimeh, Philipp Hauke
Q 19.1	Tue	14:00–14:30	f342	**Interplay of dissipative and coherent processes in engineered quantum systems** — •Anja Metelmann
Q 34.1	Wed	14:00–14:30	e214	**Zooming in on Fermi Gases in Two Dimensions** — •Philipp Preiss, Luca Bayha, Jan Hendrik Becher, Marvin Holten, Ralf Klemt, Philipp Lunt, Keerthan Subramanian, Selim Jochim
Q 49.1	Thu	14:00–14:30	e214	**New physical concepts: Fermionic Exchange Force and Bose-Einstein Force** — •Christian Schilling
Q 52.1	Thu	14:00–14:30	f442	**Long-range interactions between polar molecules and Rydberg atoms** — •Martin Zeppenfeld

Invited talks of the joint symposium SYCU

See SYCU for the full program of the symposium.

SYCU 1.1	Mon	11:00–11:30	e415	**Photoelectron circular dichroism in the light of resonance enhanced multi-photon ionization** — •Thomas Baumert
SYCU 1.2	Mon	11:30–12:00	e415	**New strategies for controlled chirality from the rovibrational dynamics of molecules** — •Andrey Yachmenev
SYCU 1.3	Mon	12:00–12:30	e415	**Time-dependency in Photoelectron Circular Dichroism: from femtosecond scale to attosecond** — •Valerie Blanchet
SYCU 1.4	Mon	12:30–13:00	e415	**Synthetic chiral light for efficient control of chiral light-matter interaction** — •David Ayuso, Ofer Neufeld, Andres F. Ordonez, Piero Decleva, Gavriel Lerner, Oren Cohen, Misha Ivanov, Olga Smirnova

Invited talks of the joint symposium SYAI

See SYAI for the full program of the symposium.

SYAI 1.1	Mon	14:00–14:30	e415	**Atom interferometry and its applications for gravity sensing** — •Franck Pereira dos Santos, Luc Absil, Romain Caldani, Xiaobing Deng, Romain Karcher, Sébastien Merlet, Raphaël Piccon, Sumit Sarkar
SYAI 1.2	Mon	14:30–15:00	e415	**Atom interferometry for advanced geodesy and gravitational wave observation** — •Philippe Bouyer
SYAI 1.3	Mon	15:00–15:30	e415	**Fundamental physics with atom interferometry** — •Paul Hamilton
SYAI 1.4	Mon	15:30–16:00	e415	**Atoms and molecules interacting with light** — •Lucia Hackermüller

Invited talks of the joint symposium SYAD

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	11:00–11:30	e415	**Electron Pulse Control with Terahertz Fields** — •Dominik Ehberger
SYAD 1.2	Tue	11:30–12:00	e415	**Laser-Based High-Voltage Metrology with ppm Accuracy** — •Kristian König, Christopher Geppert, Phillip Imgram, Jörg Krämer, Bernhard Maass, Johann Meisner, Ernst Otten, Stephan Passon, Tim Ratajczyk, Johannes Ullmann, Wilfried Nörtershäuser
SYAD 1.3	Tue	12:00–12:30	e415	**Structured singular light fields** — •Eileen Otte
SYAD 1.4	Tue	12:30–13:00	e415	**Coherent Coupling of a Single Molecule to a Fabry-Perot Microcavity** — •Daqing Wang

Invited talks of the joint symposium SYQL

See SYQL for the full program of the symposium.

SYQL 1.1	Thu	11:00–11:30	e415	**The unity of physics: the beauty and power of spectroscopy** — •Paul Julienne
SYQL 1.2	Thu	11:30–12:00	e415	**Using spectroscopy to explore the Rb_2 molecule and its formation** — •Johannes Hecker Denschlag
SYQL 1.3	Thu	12:00–12:30	e415	**Cold molecules: a chemistry kitchen for physicists** — •Olivier Dulieu
SYQL 1.4	Thu	12:30–13:00	e415	**The birth of a degenerate Fermi gas of molecules** — •Jun Ye

Invited talks of the joint symposium SYCM

See SYCM for the full program of the symposium.

SYCM 1.1	Fri	11:00–11:30	e415	**Trapped Laser-cooled Molecules for Quantum Simulation, Particle Physics, and Collisions** — •John Doyle
SYCM 1.2	Fri	11:30–12:00	e415	**Cold polyatomic molecules** — •Gerhard Rempe
SYCM 1.3	Fri	12:00–12:30	e415	**Collisions between laser-cooled molecules and atoms** — •Michael Tarbutt
SYCM 1.4	Fri	12:30–13:00	e415	**Collisions between cold molecules in a superconducting magnetic trap** — •Edvardas Narevicius

Sessions

Q 1.1–1.2	Sun	16:00–18:00	b305	**Tutorial Chirality (joint session AKjDPG/Q)**
Q 2.1–2.7	Mon	11:00–12:45	a310	**Optomechanics**
Q 3.1–3.7	Mon	11:00–13:00	e001	**Quantum Information (Concepts and Methods) I**
Q 4.1–4.8	Mon	11:00–13:00	e214	**Quantum gases (Fermions) I**
Q 5.1–5.7	Mon	11:00–13:00	f303	**Ultracold atoms, ions, and BEC I (joint session A/Q)**
Q 6.1–6.7	Mon	11:00–13:00	f342	**Quantum Effects (Disorder and Entanglement)**
Q 7.1–7.7	Mon	14:00–16:00	a310	**Nano-Optics (Microscopy and Plasmonics)**
Q 8.1–8.8	Mon	14:00–16:00	e001	**Quantum Information (Concepts and Methods) II**
Q 9.1–9.7	Mon	14:00–16:00	e214	**Quantum gases (Bosons) I**
Q 10.1–10.7	Mon	14:00–16:00	f303	**Ultra-cold atoms, ions, and BEC II (joint session A/Q)**
Q 11.1–11.8	Mon	14:00–16:00	f342	**Quantum Optics I**
Q 12.1–12.8	Mon	14:00–16:00	f442	**Quantum Effects**
Q 13.1–13.70	Mon	16:30–18:30	Empore Lichthof	**Posters: Quantum Optics and Photonics I**
Q 14.1–14.8	Tue	11:00–13:00	a310	**Precision Measurements and Metrology**
Q 15.1–15.7	Tue	11:00–13:00	e214	**Quantum gases (Bosons) II**
Q 16.1–16.8	Tue	14:00–16:00	e001	**Quantum Information (Concepts and Methods) III**
Q 17.1–17.8	Tue	14:00–16:00	e214	**Quantum gases (Bosons) III**
Q 18.1–18.7	Tue	14:00–16:00	f303	**Ultracold atoms, ions, and BEC III (joint session A/Q)**
Q 19.1–19.7	Tue	14:00–16:00	f342	**Quantum Optics II**
Q 20.1–20.7	Tue	14:00–15:45	f435	**Ultrashort Laser Pulses and Biophotonics**
Q 21.1–21.7	Tue	14:00–16:00	f442	**Ultracold Atoms (Trapping and Cooling)**
Q 22.1–22.67	Tue	16:30–18:30	Empore Lichthof	**Posters: Quantum Optics and Photonics II**
Q 23.1–23.7	Wed	11:00–13:00	a310	**Nano-Optics (Single Quantum Emitters) I**

Q 24.1–24.7	Wed	11:00–13:00	e001	**Quantum Information (Quantum Computing)**
Q 25.1–25.8	Wed	11:00–13:00	e214	**Quantum gases (Bosons) IV**
Q 26.1–26.7	Wed	11:00–13:00	f303	**Ultracold atoms, ions, and BEC IV (joint session A/Q)**
Q 27.1–27.8	Wed	11:00–13:00	f342	**Quantum Optics III**
Q 28.1–28.7	Wed	11:00–12:45	f435	**Precision Measurements and Metrology (Gravity)**
Q 29.1–29.8	Wed	11:00–13:00	f442	**Quantum Effects (Entanglement and Decoherence)**
Q 30	Wed	13:00–14:00	f342	**Annual General Meeting**
Q 31.1–31.1	Wed	13:10–13:55	f303	**Lunch talk: German Research Foundation (DFG) (joint session A/K/P/MO/MS/Q)**
Q 32.1–32.8	Wed	14:00–16:00	a310	**Precision Measurements and Metrology (Optical Clocks)**
Q 33.1–33.7	Wed	14:00–16:00	e001	**Quantum Information (Concepts and Methods) IV**
Q 34.1–34.7	Wed	14:00–16:00	e214	**Quantum gases (Fermions) II**
Q 35.1–35.5	Wed	14:00–15:15	f102	**Cold Molecules I (joint session MO/Q)**
Q 36.1–36.8	Wed	14:00–16:00	f342	**Ultracold plasmas and Rydberg systems I (joint session Q/A)**
Q 37.1–37.7	Wed	14:00–15:45	f435	**Ultrashort Laser Pulses**
Q 38.1–38.8	Wed	14:00–16:00	f442	**Quantum Effects (QED) I**
Q 39.1–39.61	Wed	16:30–18:30	Empore Lichthof	**Posters: Quantum Optics and Photonics III**
Q 40.1–40.7	Thu	11:00–13:00	a310	**Precision Measurements and Metrology (Atom Interferometry)**
Q 41.1–41.7	Thu	11:00–13:00	e001	**Quantum Information (Quantum Communication and Quantum Repeater) I**
Q 42.1–42.7	Thu	11:00–13:00	f303	**Ultracold atoms, ions, and BEC V (joint session A/Q)**
Q 43.1–43.8	Thu	11:00–13:00	f342	**Quantum Optics and Photonics**
Q 44.1–44.8	Thu	11:00–13:00	f435	**Laser Development and Applications**
Q 45.1–45.8	Thu	11:00–13:00	f442	**Quantum Effects (QED) II**
Q 46.1–46.8	Thu	14:00–16:00	a310	**Nano-Optics (Single Quantum Emitters) II**
Q 47.1–47.6	Thu	14:00–15:45	a320	**Ultra-cold plasmas and Rydberg systems II (joint session A/Q)**
Q 48.1–48.7	Thu	14:00–16:00	e001	**Quantum Information (Quantum Communication and Quantum Repeater) II**
Q 49.1–49.7	Thu	14:00–16:00	e214	**Quantum gases (Miscellaneous)**
Q 50.1–50.6	Thu	14:00–15:45	f303	**Ultra-cold atoms, ions, and BEC VI (joint session A/Q)**
Q 51.1–51.8	Thu	14:00–16:00	f342	**Quantum Optics IV**
Q 52.1–52.6	Thu	14:00–15:45	f442	**Cold Molecules II (joint session Q/MO)**
Q 53.1–53.6	Thu	16:30–18:30	Empore Lichthof	**SYCM: Contributed posters for the Symposium Hot topics in cold molecules: From laser cooling to quantum resonances**
Q 54.1–54.53	Thu	16:30–18:30	Empore Lichthof	**Posters: Quantum Optics and Photonics IV**
Q 55.1–55.8	Fri	11:00–13:00	a310	**Matter Wave Optics**
Q 56.1–56.7	Fri	11:00–13:00	b305	**Ultra-cold plasmas and Rydberg systems III (joint session A/Q)**
Q 57.1–57.7	Fri	11:00–13:00	e001	**Quantum Information (Quantum Repeater)**
Q 58.1–58.7	Fri	11:00–13:00	e214	**Quantum gases (Bosons) V**
Q 59.1–59.7	Fri	11:00–13:00	f303	**Ultra-cold atoms, ions, and BEC VII (joint session A/Q)**
Q 60.1–60.8	Fri	11:00–13:00	f442	**Quantum Effects (Cavity QED)**
Q 61.1–61.5	Fri	14:00–15:15	e415	**SYCM: Contributed talks for the Symposium Hot topics in cold molecules: From laser cooling to quantum resonances**
Q 62.1–62.8	Fri	14:00–16:00	f102	**Control (joint session MO/Q)**

Annual General Meeting of the Quantum Optics and Photonics Division

Wednesday 13:00–14:00 f342

- Bericht
- Verschiedenes

Q 1: Tutorial Chirality (joint session AKjDPG/Q)

Time: Sunday 16:00–18:00 Location: b305

Tutorial Q 1.1 Sun 16:00 b305
Photoionization with polarization-shaped ultrashort laser pulses — •Matthias Wollenhaupt — Carl von Ossietzky Universität Oldenburg, Institut für Physik, Oldenburg

Nowadays, multiphoton ionization (MPI) using advanced light sources and sophisticated detection techniques is investigated to observe and control ultrafast quantum dynamics. In this tutorial, we present an introduction to the coherent control of photoionization with ultrashort laser pulses and give an overview on experimental techniques for femtosecond laser pulse shaping and tomographic reconstruction of 3D photoelectron momentum distributions. Based on relevant experiments, we will discuss the underlying physical mechanisms of controlled MPI. In the first experiment, phase-locked double pulse sequence laser pulses are used to control interferences in the momentum distribution of free electron wave packets [1]. We introduce non-perturbative control by manipulation of dressed state population dynamics through the optical phases. The main part of the tutorial deals with 3D control of the momentum distribution of free electron wave packets. We discuss the creation of vortex-shaped photoelectron momentum distributions with counterrotating circularly polarized femtosecond laser pulses [2] and highlight experiments with bichromatic carrier-envelop phase-stable polarization-tailored laser pulses to generate c7 rotationally symmetric and asymmetric momentum distributions [3].

[1]M. Wollenhaupt et al., Phys. Rev. Lett. 89, 173001 (2002)
[2]D. Pengel et al., Phys. Rev. Lett. 118, 053003 (2017)
[3]S. Kerbstadt et al., Nat. Comm. 10, 658 (2019)

Tutorial Q 1.2 Sun 17:00 b305
The orbital angular momentum of light — •Giacomo Sorelli — Département ElectroMagnétisme et Radar, Onera - Palaiseau - France — Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, Paris, France

Light carries energy, as well as linear and angular momenta. While the energy and the linear momentum were already understood in the second half of the nineteenth century, the history of the angular momentum of light is more recent. The angular momentum of an electromagnetic wave can be decomposed into two parts: a spin contribution associated with the vectorial nature of the electromagnetic field, and an orbital contribution which is related to the light's spatial intensity and phase profiles. The spin component of light was already studied in the thirties by Beth, who established a connection between angular momentum and circular polarisation. On the contrary, the orbital contribution was not investigated before the 1990s when Allen and coworkers showed that some paraxial light beams carry a well defined orbital angular momentum (OAM). These beams have a very peculiar spatial profile, which is characterised by a central dark area around the beam axis and a spiral phase front. In this talk, I first introduce the angular momentum of the electromagnetic field from a classical electrodynamics' viewpoint and present some paraxial light beams carrying OAM. I then quantise the electromagnetic field and discuss some quantum properties of the angular momentum of photons. Finally, I describe how OAM-carrying photons are produced in the laboratory and discuss some of their applications in quantum information.

Q 2: Optomechanics

Time: Monday 11:00–12:45 Location: a310

Q 2.1 Mon 11:00 a310
Motional quantum ground state of a levitated nanoparticle from room temperature — •Uros Delic[1,2], Manuel Reisenbauer[1], Kahan Dare[1,2], David Grass[1], Vladan Vuletic[3], Nikolai Kiesel[1], and Markus Aspelmeyer[1,2] — [1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, 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 — [3]Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Optically levitated silica nanoparticles in ultra-high vacuum promise access to quantum behavior of massive objects in a room-temperature environment, with applications ranging from sensing to testing fundamental physics. We have recently developed a new experimental interface, which combines stable trapping potentials of optical tweezers with the cooling performance of optical cavities and demonstrated operation at desired experimental conditions. Furthermore, we implemented a new cooling method – cavity cooling by coherent scattering – which resolves typical technical issues of high phase noise at low motional frequencies and co-trapping by the cavity. We employ this method to demonstrate ground state cooling of the nanoparticle motion, a first step towards its full quantum control. In this talk I will compare its performance to standard (dispersive) optomechanical interaction and present our latest experimental results.

Q 2.2 Mon 11:15 a310
Levitated quantum electromechanics with charged nanoparticles — •Lukas Martinetz[1], Klaus Hornberger[1], and Benjamin A. Stickler[2] — [1]University of Duisburg-Essen, Faculty of Physics, 47048 Duisburg, Germany — [2]Imperial College London, Quantum Optics and Laser Science, London SW7 2AZ, United Kingdom

We propose an all-electrical platform for quantum experiments with charged nanoparticles of arbitrary shape and charge distribution. Each nanoparticle is levitated in a Paul trap, where its motion can be cooled resistively [1,2] and interfaced coherently with superconducting circuitry. We derive the effective potential of the ro-translational macromotion in the trap and develop a Raman-like pulsed interference protocol, which enables generating and observing spatial superpositions of the nanoparticles. This approach complements conventional optomechanical methods, providing a platform for generating entanglement between several nanoparticles and opening the door for networking levitated nanoparticles into hybrid quantum systems.

[1] Daniel Goldwater et al., Quantum Sci. Technol. 4, 024003 (2019)
[2] L. S. Brown et al., Rev. Mod. Phys. 58, 233 (1986)

Q 2.3 Mon 11:30 a310
Entangling optically levitated nanoparticles by coherent scattering — •Henning Rudolph[1], Klaus Hornberger[1], and Benjamin Stickler[1,2] — [1]Fakultät für Physik, Universität Duisburg-Essen — [2]QOLS, Imperial College London

Recently, coherent scattering of tweezer photons has been used to cool a levitated nanoparticle to the motional ground state [1]. We show how this technique can be extended to generate and verify translational entanglement between two nanoparticles, levitated in a common cavity and prepared in the ground state. Our method is based on the conditioned switching of the tweezer detuning from the blue to the red after detecting a Stokes photon. The arrival time distribution of the resulting anti-Stokes photon emission then reveals entanglement between the two particles provided its oscillation amplitude exceeds a time-dependent bound.

[1] U. Delić et al.: arXiv:1911.04406

Q 2.4 Mon 11:45 a310
Quantum States of Acoustic Modes in Optomechanical System — •Daniel Reiche[1,2], Kurt Busch[1,2], and Ryan O. Behunin[3] — [1]Humboldt-Universit\"at zu Berlin, Institut f\"ur Physik, AG Theoretische Optik \& Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany — [3]Department of Physics and Astronomy, Northern Arizona University, Flagstaff, AZ 86011, USA

Photons exchanging momentum with matter for the price of creating phonons is a remarkable feature of the interface between quantum electrodynamics and solid state physics. Under certain conditions, the decay length of the acoustic mode can become much larger than the physical dimensions of the material and the phonon exists over a surprisingly large period of time. This provides an intriguing playground for exploring and manipulating the phonon's quantum state.

In this context, we analyze the quantum properties of phonons excited in a medium due to the interaction with a coherent cavity field. For negligible dissipation, we solve the time evolution of an initially coherent state exactly and can demonstrate the existence of non-classicality.

Q 2.5 Mon 12:00 a310

Investigation of mechanical losses and photoelasticity in mechanical oscillators for applications in optomechanical devices — •Jan Meyer[1], Johannes Dickmann[2], Maik Bertke[3], Richard Norte[4], Peter Steeneken[5], Erwin Peiner[3], and Stefanie Kroker[1,2] — [1]LENA Laboratory for Emerging Nanometrology, TU Braunschweig, Pockelsstraße 14, 38106 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [3]Institut für Halbleitertechnik, TU Braunschweig, Hans-Sommer-Str. 66, D-38106 Braunschweig, Germany — [4]Kavli Institute of Nanoscience, Delft University of Technology, Delft, 2628CJ, The Netherlands — [5]Solid State Physics Laboratory, Materials Science Centre, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

The coupling of mechanical motion and optical fields is in many applications of interest like molecule detection, material investigation and sensing as well as in fundamental quantum experiments such as ground state cooling. The mechanical loss of oscillators and the photoelasticity of the involved materials are critical parameters for the coupling and thus for the design of optomechanical devices. The loss mechanisms in micro- and nanooscillators are still hardly known. In this contribution we demonstrate how temperature dependent measurements of first mechanical loss and second photoelasticity in mechanical oscillators perform. We present measurement results on silicon and diamond which are supported by finite element modelling and semi-analytical models.

Q 2.6 Mon 12:15 a310

Quantum tennis-racket dynamics of nanoscale rigid rotors — Yue Ma[1], Kiran Khosla[1], •Benjamin A. Stickler[1,2], and M. S. Kim[1] — [1]Imperial College London, London, United Kingdom — [2]University of Duisburg-Essen, Duisburg, Germany

We identify and discuss a quantum interference effect in the torque-free rotations of an asymmetric rigid body rapidly revolving around its mid-axis. The effect is based on the fact that the classical rotations around the mid-axis are unstable, leading to a pronounced quantum signature in the form of persistent periodic flipping between two opposite orientations. These quantum coherent oscillations persist much longer than their classical counterpart, even in the limit that millions of angular momentum states are occupied. We discuss how they can be observed with optically levitated nanoparticles.

Q 2.7 Mon 12:30 a310

Full time evolution of interacting harmonic oscillators in the ultra-strong coupling regime — •David Edward Bruschi[1] and Andreas Wolfgang Schell[2] — [1]Theoretical Physics, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute of Solid State Physics, Leibniz Universität Hannover, 30167 Hannover, Germany

In this work we study the time evolution of an ideal system composed of two coupled harmonic oscillators in the strong coupling regime. We solve the dynamics analytically by employing specifically developed tools to decouple the time-evolution operator induced by quadratic Hamiltonians. We use the solution to compute quantities of interest and compare them with the analogue classical solution. We also show that the full time evolution is equivalent to a specific series of beam-splitters and single mode squeezers. This allows for the system to be simulated with simple linear optics implementations. Applications to theory and experiments are also discussed.

Q 3: Quantum Information (Concepts and Methods) I

Time: Monday 11:00–13:00 Location: e001

Group Report Q 3.1 Mon 11:00 e001

Breaking Symmetries in Quantum Control Engineering: Principles and Applications — •Thomas Schulte-Herbrüggen[1], Ville Bergholm[1], Witlef Wieczorek[2], Michael Keyl[3], Frederik vom Ende[1], and Amit Devra[1] — [1]Dept. Chem., TU-Munich (TUM), Munich, Germany — [2]Dept. Microtechnology and Nanoscience, Chalmers University of Technology, Sweden — [3]Dahlem Centre for Complex Quantum Systems, FU Berlin, Germany

In emerging quantum technologies, quantum optimal control is often key to unlock the full potential of experimental set-ups.

For quantum engineering, our Lie frame of quantum systems theory provides full symmetry assessment of controllability, accessibility and reachability. In view of quantum sensing, here we focus the same tools on observability and tomographiability.

We see which symmetries to break to get a better handle both on the preparation and the detection of states. Principles are put into practice by optimal control.

Our recent proposal for an optomechanical oscillator extended by a two-level atom is a perfect illustration: without breaking the system symmetries of the optomechanical oscillator, one can only interconvert *within* classes of states of the same Wigner negativity. Coupling to the atom breaks the symmetry and thus allows to go *between* them, e.g., from Gaussian states to non-classical ones.

Worked examples thus elucidate guiding principles for quantum technologies 2.0.

Q 3.2 Mon 11:30 e001

Optimal Control: Scaling of the Control with System Size — •Matthias Mueller — Institute of Quantum Control, Peter Grünberg Institut, Forschungszentrum Jülich

Driving a quantum system with control pulses designed by Optimal Control Theory can considerably speed up desired operations like state transfer or gates and enhance the fidelity of the operations [1]. As the system size scales up, however, more resources (e.g. bandwidth, number of control parameters) are needed to control the system and the complexity of the control task grows [2]. In my contribution I will present the DCRAB algorithm [3] as an optimal control tool that allows to engineer such complex control pulses also under the action of constraints [3]. A proper choice of the control objective can decrease the effective number of parameters needed to achieve the control task [4,5]. A similar effect can be achieved by dynamically tailoring the system into subsystems relevant to the control task, e.g. by Quantum Zeno Interactions.

[1] C. Brif, R. Chakrabarti, and H. Rabitz, N. J. Phys. 12, 075008 (2010) [2] S. Lloyd, S. Montangero, PRL 113, 010502 (2014) [3] N. Rach, MMM, T. Calarco, S. Montangero, PRA 92, 052343 (2015) (ES) [4] MMM, T. Pichler, S. Montangero, T. Calarco, Appl. Phys. B, 122:104 (2016) [5] MMM, D.M. Reich, M. Murphy, H. Yuan, J. Vala, K.B. Whaley, T. Calarco, C.P. Koch, Phys. Rev. A 84, 042315 (2011)

Q 3.3 Mon 11:45 e001

Sampling scheme for neuromorphic simulation of entangled quantum systems — •Stefanie Czischek, Martin Gärttner, and Thomas Gasenzer — Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany

It has been shown recently that a large class of quantum many-body states can be represented efficiently by artificial neural networks. Furthermore, neural network architectures can be implemented in a controlled manner by means of analog hardware setups. This opens the prospect that neuromorphic computers can be used to efficiently emulate quantum many-body systems. We propose a phase-reweighted sampling scheme to draw spin states from the network-encoded distribution on neuromorphic hardware, such as the BrainScaleS system. Combining this scheme with a deep-neural-network ansatz representing quantum spin-1/2 states allows for measurements in various orthogonal spin bases. We apply the scheme to small systems with non-classical features to show that quantum entanglement can be simulated using the classical stochastic networks.

Q 3.4 Mon 12:00 e001

Statistical characterization of multipartite entanglement with moments of random correlations — •Tobias Nauck, Heinz-Peter Breuer, and Andreas Ketterer — Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Characterizing the entanglement of an unknown multipartite quantum state usually requires a number of appropriately chosen local measurements that are aligned with respect to a previously shared common reference frame. While such methods work well for small multipartite systems, they often become impractical with increasing number of involved constituents due to the exponentially growing Hilbert space dimension. In this talk we employ a statistical approach for the detection and characterization of multipartite entanglement based on moments of correlation functions obtained from a finite number of randomized measurements. In particular, we study the scaling of the required number of measurements needed to detect entanglement in the light of statistical inaccuracies and as a function of the number of involved parties.

Q 3.5 Mon 12:15 e001

Detecting entanglement of unknown continuous variable states with random measurements — Tatiana Mihaescu[1,2], Hermann Kampermann[1], •Giulio Gianfelici[1], Aurelian Isar[2,3], and Dagmar Bruss[1] — [1]Heinrich-Heine-Universität Düsseldorf, Institut für Theoretische Physik III, D-40225 Düsseldorf, Germany — [2]Department of Theoretical Physics, National Institute of Physics and Nuclear Engineering, RO-077125 Bucharest-Magurele, Romania — [3]Faculty of Physics, University of Bucharest, RO-077125 Bucharest-Magurele, Romania

We explore the possibility of entanglement detection in continuous-variable systems by entanglement witnesses based on covariance matrices, constructible from random homodyne measurements. We propose new linear constraints characterizing the entanglement witnesses based on second moments, and use them in a semidefinite programme providing the optimal entanglement test for given random measurements. We test the method on the class of squeezed vacuum states and study the efficiency of entanglement detection in general unknown covariance matrices.

Q 3.6 Mon 12:30 e001

Proving uncertainty relations with semi-definite programming — •Timo Simnacher, Xiao-Dong Yu, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen

Heisenberg's uncertainty principle conveys a major distinction between quantum and classical physics. Since its formulation, uncertainty relations have become one of the exceptional trademarks of quantum mechanics. Beside being of fundamental importance, current experiments are indeed able to approach these universal limitations. Although extensive research has been conducted in particular in the field of quantum information theory, there is still no general understanding of uncertainty relations, especially when it comes to more than two measurement settings.

One serious obstacle hindering further advances in the theory of uncertainty relations is the non-linearity common to both, variance- and entropy-based formulations. We present a general method to linearize such relations utilizing multiple copies of the same quantum state. Using semi-definite programming techniques, we provide effective relaxations to obtain non-trivial bounds for relevant state-independent uncertainty relations. Furthermore, we formulate uncertainty relations in terms of moment matrices to achieve results independent of the explicit measurement settings. Semi-definite programs have the advantage of providing a certificate, proving the obtained bounds up to numerical precision.

Q 3.7 Mon 12:45 e001

Quantum fluctuation relations for generalized quantum measurements — •Konstantin Beyer[1], Kimmo Luoma[1], Roope Uola[2], and Walter Strunz[1] — [1]TU Dresden, Institut für Theoretische Physik — [2]University of Geneva, Group of Applied Physics

Quantum fluctuation theorems are mostly discussed in the framework of two-point measurement scenarios. The validity of the results often relies explicitly on projective measurements and tacitly on the use of Lüders instruments. From a quantum information point of view, these are severe restrictions and it is desirable to clarify to what extent they are necessary for the formulation of quantum fluctuation relations. Therefore, we broaden the view and investigate generalized quantum fluctuation theorems based on POVMs and different kinds of instruments, showing that the relations for standard two-point energy measurements can be seen as special cases of a more general class of POVM fluctuation theorems.

Q 4: Quantum gases (Fermions) I

Time: Monday 11:00–13:00 Location: e214

Q 4.1 Mon 11:00 e214

Simulationg the Mott insulator using attractive interaction — •Chun Fai Chan, Marcell Gall, Nicola Wurz, Jens Samland, and Michael Köhl — Physikalisches Institut, University of Bonn, Bonn, Germany

We investigate the particle-hole symmetry of the two-dimensional Hubbard model under a particle-hole transformation using ultracold fermionic potassium-40 confined in optical lattices. By experimentally probing the density and spin sectors of the Hubbard models with both repulsive and attractive interactions, we demonstrate a direct mapping between relevant observables. In addition, we observe a Mott-like, spin-incompressible phase in our realization of the spin-imbalanced attractive Hubbard model. Our results present a novel approach to quantum simulation by giving access to strongly-correlated phases of matter through an experimental mapping to easier detectable observables.

Q 4.2 Mon 11:15 e214

Dark state dynamics in dissipative Fermi gases — •Lukas Freystatzky[1,2] and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

Inspired by recent experiments in ultracold Ytterbium gases, reported by Sponsele *et.al., Quantum Science and Technology* **4**, 014002 (2019), we investigate the dynamics of the dissipative 1D Fermi-Hubbard model.

The dynamics is governed by the coherent evolution due to the Hamiltonian as well as an inelastic scattering process leading to two particle losses. We model this system with a Master equation formalism, for small system sizes. We expand these studies to larger system sizes by using a quantum Jump algorithm.

In our model we find dark states, i.e. eigenstates of the Hamiltonian that do not couple to the dissipative term. Depending on the initial state the system can be driven into different dark states with distinct properties. For example, a spin balanced initial state decays into highly correlated Dicke states.

Other initial states give rise to dark states with non-trivial dynamics, as we report in this presentation.

Q 4.3 Mon 11:30 e214

Detecting topology in interacting fermionic wires via post-quench observables — Andreas Haller[1], Pietro Massignan[2,3], and •Matteo Rizzi[4,5] — [1]Institute of Physics, Johannes Gutenberg University, D-55099 Mainz, Germany — [2]Departament de Fìsica, Universitat Politècnica de Catalunya, Campus Nord B4-B5, 08034 Barcelona, Spain — [3]ICFO – Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [4]Forschungszentrum Jülich, Institute of Quantum Control, Peter Grünberg Institut (PGI-8), 52425 Jülich, Germany — [5]Institute for Theoretical Physics, University of Cologne, D-50937 Köln, Germany

We exploit a simple observable called "mean chiral displacement" (MCD) for interacting fermionic wires and study numerically the interacting Su-Schrieffer-Heeger (SSH) chain by means of matrix product state calculations. In particular, we propose to study the time-evolution of a simple local quench which relates the MCD to the many-body topological invariant of the Hamiltonian for weakly-correlated interacting models. We study both a short-range correlated and a long-correlated model exhibiting topological/trivial insulators and a (trivial) symmetry breaking phase, and we link the behavior of the MCD to all three phases. We provide an experimental blueprint to obtain the long-range correlated model hosting all three phases.

Q 4.4 Mon 11:45 e214

Observing the Few-Body Precursor of a Higgs Mode — •Luca Bayha, Marvin Holten, Keerthan Subramanian, Ralf Klemt, Philipp Preiss, and Selim Jochim — Physics Institute, Heidelberg University, Germany

The competition between two scales gives rise to rich physics. For example, the finite size of mesoscopic systems results in single particle gaps and shell structures, well known from nuclear and atomic physics. Here I will present our progress on realizing such mesoscopic systems with ultracold fermions. We can prepare closed shells of up to 12 fermions in the ground state of a two dimensional trap. With the help of a Feshbach resonance we tune the interactions from a single–particle gap regime to a pairing regime. For filled shells there is a minimal required attraction for pairing to overcome the single–particle gap.

In the thermodynamic limit, the onset of pairing with increasing interaction gives rise to a quantum phase transition into the superfluid state. This is accompanied by an undamped Higgs mode. Remarkably, we observe a precursor of this mode already in the mesoscopic system consisting of six fermions. The lowest monopole excitation shows mode softening as function of the interaction strength. The non-monotonicity is the few body analogue of the gap closing at the phase transition. By measuring the atom number distribution of the excitation, we can show that it is a pair excitation as expected for the Higgs mode, since the order parameter is the pair density.

Q 4.5 Mon 12:00 e214

Slow quench in dilute attractively interacting Fermi gases: Emergence of preformed pairs — •Johannes Kombe, Jean-Sébastien Bernier, Michael Köhl, and Corinna Kollath — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We investigate the non-equilibrium behaviour of dilute attractively interacting Fermi gases subject to slow ramps of their internal interaction strength, identifying three different dynamical regimes as a function of ramp duration. We demonstrate that, via slow quenches, one can dynamically tune the coherence between pairs, and thus control the magnitude of the superconducting order parameter. In fact, we show that one can even engineer a non-equilibrium state made of preformed pairs.

Q 4.6 Mon 12:15 e214

Assembling a Strongly Correlated Fermi Superfluid one Atom at a Time — •Marvin Holten, Luca Bayha, Keerthan Subramanian, Carl Heintze, Philipp Preiss, and Selim Jochim — Physics Institute, University of Heidelberg, Germany

Strong correlations between Fermions lie at the heart of many open questions concerning quantum matter that remain unresolved to this day. Examples are quark gluon plasmas, strange metals or high temperature superconductors. Effective descriptions of such systems in terms of weakly interacting constituents are unknown and the strong fermionic correlations must be considered.

In our experiment, we take a novel approach to study a strongly interacting two-dimensional Fermi superfluid by starting from very small systems, prepared deterministically in the ground state. We find evidence for the presence of a few body precursor of the superfluid phase transition and study its dependence on particle number. In this talk, I present first results obtained by applying a time-of-flight imaging technique, both spin and single particle resolved, to this system. This enables us to extract arbitrary N-body correlations of our many-body state. First measurements reveal strong high-order momentum correlations even between identical, non-interacting, Fermions. These manifest due to Pauli's principle, leading to particular geometric arrangements of trapped Fermions also referred to as Pauli Crystals.

We plan to extend these measurements to both interacting systems and larger particle numbers in the future to tackle the issue of the pairing mechanism in strongly interacting Fermi gases.

Q 4.7 Mon 12:30 e214

Unsupervised Machine Learning of Topological Phase Transitions from Experimental Data — •Niklas Käming[1], Benno Rem[1,2], Matthias Tarnowski[1,2], Luca Asteria[1], Nick Fläschner[1], Christoph Becker[1,3], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]ILP - Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]ZOQ - Zentrum für Optische Quantentechnologien, Universität Hambur g, Luruper Chaussee 149, 22761 Hamburg, Germany

Machine learning techniques such as artificial neural networks are currently revolutionizing many technological areas and have also proven successful in quantum physics applications. Here we apply unsupervised learning techniques such as deep convolutional autoencoders to identify phase transition from experimental data. We map out the complete two-dimensional topological phase diagram of the Haldane model with an unsupervised learning scheme applied to experimental momentum space density images of ultracold quantum gases. Our work points the way to experimentally explore unknown complex phase diagrams without prior knowledge of the underlying theoretical structure.

Q 4.8 Mon 12:45 e214

Experimental Quantum State Reconstruction of Few-Fermion Systems via Neural Networks — •Laurin Fischer[1], Marcel Neugebauer[1], Martin Gärttner[2], Philipp Preiss[1], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

For reconstructing the state of a many-body quantum system, the number of required measurements typically scales exponentially with the system size. Machine learning techniques based on generative models have emerged in recent years as an intriguing tool to tackle this challenge. To this end, an artificial neural network is trained to encode the probability distribution of an informationally complete measurement via unsupervised learning.

This approach has been established through numerical simulations of spin models, showing promising scaling of computational resources. In order to investigate the practical feasibility of these methods, we aim to apply them to realistic experimental settings.

In this talk, we demonstrate a successful neural-network state representation of a system of few fermionic ^6Li atoms in a double-well potential of optical tweezers. The training data is generated by measurements of in-situ populations in real space and correlation measurements in momentum-space, allowing us to benchmark this approach against more conventional techniques of state reconstruction, such as maximum likelihood.

Q 5: Ultracold atoms, ions, and BEC I (joint session A/Q)

Time: Monday 11:00–13:00 Location: f303

Invited Talk Q 5.1 Mon 11:00 f303

Creation of ultracold bosonic ^{23}Na^{39}K ground state molecules — •Kai Konrad Voges, Philipp Gersema, Torsten Hartmann, Mara Meyer zum Alten Borgloh, Torben Alexander Schulze, Alessandro Zenesini, and Silke Ospelkaus — Universität Hannover, Institut für Quantenoptik

Heteronuclear ground state molecules, with their large electric dipole moments, are an excellent platform for the investigation of fascinating dipolar quantum phenomena.

Bialkali ground state molecules are assembled from an ultracold atomic quantum gas mixture by utilizing Feshbach molecule association and subsequent stimulated Raman adiabatic passage (STIRAP) to the ground state.

In this talk we present the coherent creation of bosonic ^{23}Na^{39}K rovibrational ground state molecules following this pathway. We perform radio frequency pulses to populate a weakly bound molecular state close to a broad Feshbach resonance. We analyze the molecule creation efficiency with respect to the atom number ratio and radio frequency pulse duration. After that, we transfer the Feshbach molecules to a single spin-polarized hyperfine ground state using STIRAP through strongly coupled $c^3\Sigma(v=30)$ and $B^1\Pi(v=8)$ states, which we investigated spectroscopically beforehand. In this way we reach efficiencies of up to 70 %. We model the transfer process by incorporating multiple states from the excited state manifold and find a good agreement with our experimental results.

Q 5.2 Mon 11:30 f303

Spin-rotation coupling in p-wave Feshbach resonances — •Manuel Gerken[1], Binh Tran[1], Eleonora Lippi[1], Bing Zhu[1,2], Stefan Häfner[1], Juris Ulmanis[1], Eberhard Tiemann[3], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We report on the observation of spin-rotation coupling in p-wave Feshbach resonances in an ultracold mixture of fermionic ^{6}Li and bosonic ^{133}Cs. In addition to the doublet structure in the Feshbach spectrum due to spin-spin interaction, we observe a triplet structure of different m_ℓ states by magnetic field dependent atom-loss spectroscopy. Here, the m_ℓ states are projections of the pair-rotation angular momentum ℓ on the external magnetic field. Through comparison with coupled-channel calculations, we attribute the observed splitting of the $m_\ell = \pm 1$ components to electron spin-rotation coupling. Comparison with an oversimplified model, estimating the spin-rotation coupling by describing the weakly bound close-channel molecular state with the perturbative multipole expansion, reveals the significant contribution of the molecular wavefunction at short internuclear distances. Our findings highlight the potential of Feshbach resonances in providing precise information on short- and intermediate-range molecular couplings and wavefunctions. We also present measurements of spin-spin coupling in p-wave Feshbach resonances in a Li^6 mixture.

Q 5.3 Mon 11:45 f303

Tune-out and magic wavelengths for the ^{23}Na^{40}K molecule — •Roman Bause[1], Xing-Yan Chen[1], Andreas Schindewolf[1], Ming Li[2], Marcel Duda[1], Svetlana Kotochigova[2], Immanuel Bloch[1,3], and Xin-Yu Luo[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching — [2]Department of Physics, Temple University, Philadelphia, Pennsylvania 19122, USA — [3]Ludwig-Maximilians-Universität, 80799 München

State-dependent optical dipole traps for ultracold atoms or molecules have wide application in quantum engineering and precision measurements. One extreme case is the tune-out condition, where the light shift of one state vanishes while the other one remains finite. Another extreme case is the magic condition, where the light shifts of both states are identical. We demonstrate a versatile, rotational-state dependent optical dipole trap for the ground-state ^{23}Na^{40}K molecule and its first rotationally excited state. Close to a low-lying, narrow molecular transition, we experimentally determined a tune-out and a magic frequency. Because these frequencies are less than 10 GHz apart, it is possible to create both types of trap as well as any intermediate trap configuration with the same laser system and switch between them during an experimental cycle. We propose that the rotational-state dependent trap can be used for evaporative cooling of polar molecules or investigation of their collisional properties.

Q 5.4 Mon 12:00 f303

Efimov physics in strongly mass-imbalanced atom-dimer gases — •Panagiotis Giannakeas[1] and Chris H. Greene[2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Department of Physics and Astronomy, Purdue University, Indiana, USA

Three-body collisions in a two-species ultracold gases possess unique Efimovian idiosyncrasies. Indeed, for this particular colliding complex the magnitude and the sign intra- and inter-species scattering lengths can render an inherently different Efimovian landscape where the corresponding recombination spectra exhibit Efimov resonances intertwined with Stueckelberg suppression effects. Our current studies exploit these unique attributes of Efimov physics in mass-imbalanced systems by investigating the relevant scattering processes in atom-dimer gases. In particular, our analysis shows that the corresponding atom-dimer collisions are strongly enhanced when an Efimov bound state from the energetically closed three-body channel lies in the atom-dimer continuum, i.e. energetically open channel. Namely, our study demonstrates that in mass-imbalanced atom-dimer gases exists a series of atom-dimer resonances which fulfill a Fano-Feshbach scenario. In addition, we highlight the pivotal role of Stueckelberg physics on the width of the atom-dimer resonances where by adjusting the intra-species scattering length the atom-dimer continuum fully decouples from the Efimov states. Finally, our analysis addresses the universal aspects of this type of atom-dimer resonances, as well as, the importance of the Van der Waals physics.

Q 5.5 Mon 12:15 f303

Autodetachment reaction dynamics in anion-atom reactions. — •Saba Zia Hassan[1,2], Jonas Tauch[1], Milaim Kas[4,5], Markus Nötzold[3], Henry Lopez[1], Eric Endres[1], Roland Wester[3], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut Heidelberg, INF 226, 69120 Heidelberg — [2]International Max Planck Research School for Quantum Dynamics, Max Planck Institute for Nuclear Physics, 69117 Heidelberg — [3]Institut für Ionenphysik und Angewandte Physik, Technikerstraße 25/3, 6020 Innsbruck — [4]Département de Chimie, Faculté des Sciences, Université Libre de Bruxelles (ULB), 1050 Brusseles — [5]Deutsches Elektronen-Synchrotron (DESY), 22607 Hamburg

Associative detachment (AD) reactions play a key role in the destruction of anions to form neutral molecules in chemical networks, like interstellar medium, Earth's ionosphere and biochemistry. Here, we investigate AD reactions involving a closed-shell anion OH^- and rubidium atoms in a hybrid atom-ion trap. The overlap of atoms and anions leads to elastic and inelastic collisions, cooling the external and internal degrees of freedom respectively. Ab-initio calculations also predict the occurrence of AD reaction, i.e. $Rb+OH^- \rightarrow RbOH$. A detailed experimental investigation of AD reactions can serve as a stringent test on the effective core potentials used in theoretical studies. Furthermore, with a precise control on the fraction of electronically excited rubidium in the ensemble, the dynamics of quantum state dependent reactive collisions can be studied. In this contribution the latest results will be presented.

Q 5.6 Mon 12:30 f303

A new ultracold atomic mixture experiment : SoPa — •Rohit Prasad Bhatt, Lilo Höcker, Jan Kilinc, and Fred Jendrzejewski — Kirchhoff-Institute for Physics, Im Neuenheimer Feld 227, D-69120 Heidelberg

Ultracold atomic gases present a high control over experimental parameters which makes them an ideal candidate to simulate a wide variety of physical systems. Ultracold atomic mixtures expand these horizons by covering an even greater range of quantum many body phenomena like dynamical gauge fields, quantum thermodynamic cycles etc. In this talk, I present the new Na-K experiment at Heidelberg, which we are setting up as a platform to study some of those problems.

Q 5.7 Mon 12:45 f303

Squeezed-field path-integral description of a BEC — •Ilias Mir Heliassudin Seifie[1,2], Vijay Pal Singh[1,2,3], and Ludwig Mathey[1,2,3] — [1]Center for Optical Quantum Technologies, University of Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Germany — [3]Institute of Laser Physics, University of Hamburg, Germany

We propose a generalization of the Feynman path integral using squeezed coherent states. In fact, the introduction of the squeezing parameter into the path integral enhances the adaptability of the theoretical model to the physical system. Therefore, our method can be applied to any analytical and numerical approach that is based on the path-integral representation. We apply this approach to the dynamics of Bose-Einstein condensates. In the low energy regime of a BEC, we obtain a generalization of the linearized Gross Pitaevskii equation, containing coherent and squeezing fields, and a description of second sound in weakly interacting condensates as a squeezing oscillation of the order parameter. In the higher energy and finite temperature regime, we analyze the coupling between the two fields and develope corresponding numerical and analytical methods.

Q 6: Quantum Effects (Disorder and Entanglement)

Time: Monday 11:00–13:00 Location: f342

Invited Talk Q 6.1 Mon 11:00 f342

Hilbert space structure of eigenstates in many-body quantum systems — •Alberto Rodríguez — Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain

Basic features of a quantum system, such as its dynamical behaviour or its stability to perturbations, depend crucially on the statistical properties of its spectrum and eigenstates. In this talk, we will explore the characterization of the eigenstate structure in Hilbert space for interacting particles, borrowing the tools from multifractal analysis, which has a long history in the field of Anderson localization. We will discuss to which extent such formalism is able to unveil the complexity of many-body eigenstates and capture the existence of different 'phases' in the system [1-3], touching also upon the underlying connection with the emergence of spectral chaos [4].

[1] J. Lindinger, A. Buchleitner, A. Rodríguez, PRL 122, 106603 (2019).
[2] D. J. Luitz, F. Alet, N. Laflorencie, PRL 112, 057203 (2014).
[3] N. Macé, F. Alet, N. Laflorencie, PRL 123, 180601 (2019).
[4] A. R. Kolovsky, A. Buchleitner, Europhys. Lett., 68, 632 (2004).

Q 6.2 Mon 11:30 f342

Extending the SSH Model Beyond Nearest Neighbour Interactions — •Ciarán McDonnell[1] and Beatriz Olmos[2] — [1]Centre for the mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD, UK. — [2]Auf der Morgenstelle 14 72076 Tübingen

The Su-Schrieffer-Heeger (SSH) model was first used to describe the transport dynamics of polyacetylene in 1979. The nearest neighbour model has since effectively described the dynamics in a wide range of systems. These systems as a result can exhibit topological phases and are known as topological insulators. Little work has been done to extend the SSH model beyond the nearest neighbour regime, with none of the work extending beyond three nearest neighbours. We use a nanofiber waveguide coupled to two-level atoms to theoretically explore an arbitrary number of interactions. We first look at the case where the system is chiral symmetric find a general criterion for the topological phases of the system and find the corresponding edge states. We then extend to the non-chiral symmetric case and investigate how this affects the presence of edge states.

Q 6.3 Mon 11:45 f342

Bose-Einstein Condensation of Light in Disordered Nano Cavities at Room Temperature — •Andris Erglis[1] and Andrea Fratalocchi[2] — [1]Institute of Physics, Albert-Ludwigs University of Freiburg, Germany — [2]PRIMALIGHT, King Abdullah University of Science and Technology (KAUST), Saudi Arabia

Bose-Einstein condensation is a macroscopic occupation of bosons in the lowest energy state. For atoms, temperatures near absolute zero kelvin are required to observe this phenomenon. For photons, condensation has been demonstrated at room temperature, requiring a large number of particles and very complicated setup.

Here we study the possibility of observing BEC of light at room temperature without a constraint on the number of photons in the system by leveraging disorder in a dielectric material. We demonstrate that photons in a disordered cavity with any initial statistical distribution in the steady state will reach thermal equilibrium and undergo Bose-Einstein condensation if the temperature is sufficiently reduced. At this point the photons follow a Boltzmann distribution. The analysis is carried out by using time-dependent quantum Langevin equations, complemented by a thermodynamic analysis. Both approaches give the same expression for the critical temperature of condensation. We demonstrate that the temperature is related to the losses of the system. By only varying the strength of disorder, it is possible to change the critical temperature of the phase transition, thus making condensation possible at room temperature. This work opens up the possibility to create new types of light condensate by using disorder.

Q 6.4 Mon 12:00 f342

Observation of Non-Hermitian Anderson Transport — •Sebastian Weidemann[1], Mark Kremer[1], Stefano Longhi[2], and Alexander Szameit[1] — [1]Experimental Solid State Optics Group, Institute of Physics, University of Rostock, Germany — [2]Dipartimento di Fisica, Politecnico di Milano, Piazza L. da Vinci 32, Milano I-20133, Italy

It was a major breakthrough for the understanding of conductance in solids when Anderson showed that stochastic imperfections in crystalline lattices can result in self-trapping of a single electron via quantum interference. For the underlying mechanism, called Anderson localization, disorder is described by random changes only in the real part of the potential. We take a new perspective within the study of disorderd systems by asking whether the concepts of localization and transport carry over to the more general context of open systems when random changes occur also in the imaginary part of the potential. To this end we employ light propagation in a photonic lattice with tunable dissipation as a model system. The controllable dissipation allows to realize nearly arbitrary complex potentials. Our theoretical and experimental findings reveal a novel non-Hermitian transport mechanism: The imaginary disorder not only leads to a fully localized eigenmode spectrum like in the Hermitian case, but also causes surprising transport dynamics that is characterized by ultra-far jumps and a restoration of ballistic spreading. Beyond the experimental observation of this „Anderson Transport“, we provide a theoretical explanation by giving the analytical solution for a corresponding chain model.

Q 6.5 Mon 12:15 f342

Constructing a Light Funnel with the non-Hermitian Skin Effect — •Mark Kremer[1], Sebastian Weidemann[1], Tobias Helbig[2], Tobias Hofmann[2], Alexander Stegmaier[2], Martin Greiter[2], Ronny Thomale[2], and Alexander Szameit[1] — [1]Institut of Physics, University of Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany — [2]Department of Physics and Astronomy, Julius-Maximilians-Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

The interaction of physical systems with the environment were often considered undesired, until it was demonstrated that certain loss distributions can lead to intriguing effects, like enhanced sensing, or mode selective laser cavities. However, most of these works, especially in optics, introduce non-Hermiticity by applying tailored loss profiles, thereby restricting it to a subset of physical models. In our work, we realize non-Hermiticity by coupling anisotropy – an often neglected degree of freedom. In a periodic lattice with such anisotropic coupling, the incorporation of an interface causes all eigenmodes to localize at this interface. This *non-Hermitian skin effect* is an interesting aspect of the current debate about the validity of the bulk boundary correspondence. We experimentally implement the skin effect with a large-scale photonic mesh lattice and demonstrate the collapse of all eigenmodes at the interface, with no delocalized bulk modes remaining. As a result, the system acts as a funnel for light: Any wave packet, regardless of its original position in the lattice, is routed to the interface and remains there indefinitely.

Q 6.6 Mon 12:30 f342

Mode-independent quantum entanglement for light — •Jan Sperling[1], Armando Perez-Leija[2], Kurt Busch[2], and Christine Silberhorn[1] — [1]University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany — [2]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

Optical mode transformations, such as beam-splitter operations, can significantly alter the entanglement properties of quantum states of light. For example, such global unitary maps can generate entanglement from initially separable states, and vise versa. In this talk, we report on the construction of families of photonic states with the unique property that their entanglement is in fact preserved under arbitrary mode transformations. We develop tools to characterize the specific features of the resulting multi-photon and multi-mode states of quantum light. In contrast to most examples of optical implementations of entangled states, the type of entanglement we introduce offers a new resource of quantum correlations for quantum communications which is robust even under global mode transformations.

Q 6.7 Mon 12:45 f342

Quantum manybody systems with neural networks — •Felix Behrens, Stefanie Czischek, Martin Gärttner, and Thomas Gasenzer — KIP, Heidelberg

The idea of connecting artificial neural networks and quantum mechanics gained a lot of interest over the last years. A representation of arbitrary quantum many-body states using a specific kind of artificial neural network, the restricted Boltzmann machine, has been introduced in [1]. With a generative model approach, any state can be represented. In the framework of Positive Operator Valued Measures (POVM), time evolution eg. following Heisenberg equation, can be represented for a probability distribution. We implement this ansatz with standard machine learning techinques for Restricted Boltzmann Machine (RBM). Given some, hypothetically measured, data, the RBM facilitates fast sampling from the underlying probability. Those samples can in principle be used for a Monte-Carlo like integration of the time evolution and for measuring any operator. The next qurstion to ask is, how statistical noise in the RBM implementation violates physical constraints on the state and its expectation values and how to restrict the RBM representation to its physical subspace. [1] Juan Carrasquilla, arXiv:1810.10584, Oct 2018.

Q 7: Nano-Optics (Microscopy and Plasmonics)

Time: Monday 14:00–16:00 Location: a310

Invited Talk Q 7.1 Mon 14:00 a310

Phonon engineering and manipulation at the nanoscale — •Ilaria Zardo — Department of Physics, University of Basel, CH-4056 Basel, Switzerland

The recently growing research field called “Nanophononics” deals with the investigation and control of vibrations in solids at the nanoscale. Phonon engineering leads to a controlled modification of phonon dispersion, phonon interactions, and transport. Nonetheless, it requires new theoretical and experimental methods, especially when combined with low dimensional physics, which is one of the most promising routes for thermal management and for controlling photon-phonon and electron-phonon interactions.

In this talk, we discuss how phononic properties can be engineered in nanowires and the challenges and progresses in the measurement of phonons and phonon transport of nanostructures.

Q 7.2 Mon 14:30 a310

Coherent plasmonics: a single molecule makes a plasmonic nanoparticle more transparent — •Johannes Zirkelbach[1], Jan Renger[1], Tobias Utikal[1], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany

A plasmonic nanoparticle creates a strong extinction shadow detectable in transmission. We demonstrate that a single molecule placed in the near-field of a plasmonic particle can substantially reduce this extinction shadow, making the plasmonic particle more transparent. To achieve this, we prepare a thin molecular crystal doped with dibenzoterrylene (DBT) molecules on a nanostructured array of gold nanoantennas at liquid helium temperature. We then select individual molecules through high-resolution laser spectroscopy and investigate their near-field coupling to nearby gold nanoantennas by recording both extinction and fluorescence excitation spectra. We present a quantitative analysis of the observed spectral lines and comparison with an analytical model, revealing a coherent interaction between the light fields scattered from a molecule and a gold nanoparticle [1].

[1] J. Zirkelbach, et al., in preparation.

Q 7.3 Mon 14:45 a310

Extreme laser background suppression for resonant fluorescence of a quantum emitter — •Meryem Benelajla[1,2], Elena Kammann[1], and Khaled Karrai[1] — [1]attocube systems AG, Eglfinger Weg 2, 85540 Haar bei München — [2]LPCNO INSA CNRS UPS, 135 Av. Rangueil , 31077 Toulouse, France

Confocal microscope is widely used in quantum optics for studying resonant fluorescence properties of semiconductor nanostructures. However, such challenging measurements require the suppression of laser background by several order of magnitudes.One way to do that is to use cross polarization confocal microscopy. Normally, high quality commercial crossed polarizers allows a laser suppression down to 5 to 6 orders of magnitudes. Surprisingly, when used in combination with a confocal microscope, the extinction ratio is boosted up to 9 order of magnitudes. This unexpected but very welcome enhancement finds its origin in the Imbert-Fedorov effect, now commonly referred to as Spin Hall effect of light, which manifests itself in the reflectivity of a Gaussian laser beam off a mirror. In this presentation, we will discuss in details the physics and optics of such a remarkable effect, which we mapped in details for the first time.

Q 7.4 Mon 15:00 a310

Plasmon-assisted Purcell enhancement of silicon-vacancy color centers in diamond membranes — •Haritha Kambalathmana[1], Assegid Mengistu Flatae[1], Stefano Lagomarsino[1], Florian Sledz[1], Lukas Hunold[1], Claudio Biagini[2], Francesco Tantussi[2], Francesco De Angelis[2], and Mario Agio[1] — [1]Laboratory of Nano-Optics, University of Siegen, 57072 Siegen, Germany — [2]Istituto Italiano di Tecnologia, 16163 Genova, Italy

Ultrafast solid-state single-photon sources are desirable in quantum information science and fundamental quantum optics. Currently, we have developed techniques for the fabrication and optical characterization of single-photon sources based on silicon-vacancy (SiV) color centers in diamond [1]. We have experimentally shown that plasmonic gold nano-cones enhance the radiative decay rate by more than three orders of magnitude and boost the efficiency of quantum emitters [2]. We fabricate gold nano-cones on a commercially available atomic force microscopy probe by gold deposition followed by focused ion beam milling. The SiV centers are shallow-implanted in thin diamond membrane to provide the required dimension for near-field interaction in a controlled manner. Theoretical calculations show that the fabricated nano-cones can provide more than four orders of magnitude enhancement in the Purcell factor and a quantum efficiency of 80% [3]. References:[1] S. Lagomarsino, et al., Diam. Relat. Mater. 84, 196 (2018). [2] A. M. Flatae, et al., J. Phys. Chem. Lett. 10, 2874-2878 (2019). [3] H. Kambalathmana, et al., Proc.SPIE 11091, 1109108-1 (2019).

Q 7.5 Mon 15:15 a310

Few-cycle oscillator-based nonlinear and strong-field nanooptics — •Liping Shi[1,2], Uwe Morgner[1,2], and Milutin Kovacev[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering - Innovation AcrossDisciplines), Hannover, Germany

The study of strong-field nonlinear optical effects usually relies on a chirped-pulse amplifier system, which will unwantedly stretch the pulse duration and sacrifice the repetition rate of a seeded oscillator. Here we employ plasmonic and Mie-type optical nanoantennas to amplify the electric near-field strength of a few-cycle Ti:Sapphire oscillator, demonstrating unique advantages of the oscillator-based nonlinear and strong-field effects. First, we can produce a nanoscale ultra-broadband deep ultraviolet light source. Second, due to the giant field gradient in the vicinity of optical nanoantennas, a post-tunneling electron experiences a strong ponderomotive acceleration. This results in a novel mechanism of femtosecond near-field ablation and thin-film deposition. Third, the high-repetition rate of the low-fluence oscillator allows us to investigate some effects that require low-threshold while multi-shot exposure, such as the self-enhanced nonlinear response of silicon nanodisks resonant at anapole modes.

Q 7.6 Mon 15:30 a310

Strong coupling of single quantum dots in a plasmonic antenna at room temperature — •Hsuan-Wei Liu[1], Randhir Randhir Kumar[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University of Erlangen-Nürnberg, Erlangen, Germany

Plasmonic antennas are capable of enhancing the spontaneous emission rate of single emitters due to their strong electric field confinement [1]. It has been reported that a nanogap antenna formed by a gold nanoparticle separated from a metallic substrate by a thin dielectric gap can achieve ultra-strong enhancement [2]. When the enhanced emission rate is fast enough to compete with the room temperature dephasing and the plasmon losses rates, the emitter starts to interact coherently with the plasmon mode, bringing the system into the strong coupling regime. In this study, we demonstrate a significant enhancement of a single quantum dot coupled to a plasmonic nanogap antenna. We observe an ultrafast fluorescence lifetime less than 38 ps limited by the instrumental response function. Moreover, by controlling the position of the quantum dot with respect to the nanogap antenna, we can tune the system from the weak coupling to the strong coupling regime leading to vacuum Rabi splitting in the fluorescence spectra [3].

[1] Matsuzaki *et al.*, *Sci. Rep.* **7**, 42307 (2017). [2] Chikkaraddy *et al.*, *Nature* **535**, 127-130 (2016). [3] Liu *et al.*, *in preparation.*

Q 7.7 Mon 15:45 a310

Development of 3D Metallic Microstructures for Light Concentration — •Lei Zheng[1,2] and Bernhard Roth[1,2] — [1]Hannover Centre for Optical Technologies, Leibniz Universität Hannover, Nienburger Straße 17, 30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Discipline), Hannover, Germany

3D metallic Microstructures with symmetrically curved surfaces are developed for surface plasmon polariton (SPP) deflection and concentration with the perspective to be employed for future sensing applications. The designed structures were first fabricated on a glass substrate using two-photon polymerization (2PP), and then covered with a 60 nm thick gold film by sputtering. Surface plasmon polaritons (SPPs) propagating on the fabricated structure are generated through a straight line on the structure surface. Leakage radiation microscopy (LRM) is used here for the excitation and observation of SPPs. When focusing the laser beam onto the straight excitation line, SPPs can be excited towards both sides of the line. The characterization results on different structures have shown that SPPs can be deflected and partly concentrated when they propagate around the raised part of the metallic structure. The maximum electromagnetic energy concentration can be reached when SPPs propagate towards the center of the raised part of the structure. An investigation on the energy concentration performance of the proposed metallic structures with respect to different structure profiles is analytically and experimentally carried out. The work towards realization of novel optical sensing devices is discussed.

Q 8: Quantum Information (Concepts and Methods) II

Time: Monday 14:00–16:00 Location: e001

Q 8.1 Mon 14:00 e001

Quantum trajectories—measurement interpretation — Nina Megier[2], Walter T. Strunz[1], and •Kimmo Luoma[1] — [1]ITP, TU Dresden, Dresden, Germany — [2]Dipartimento di Fisica, Università degli Studi di Milano,Italy

Quantum measurements and the associated state changes are properly described in the language of instruments. We investigate the properties of a time continuous family of instruments associated with the recently introduced family of general Gaussian non-Markovian stochastic Schrödinger equations. We stipulate the conditions for the family of instruments to be consistent with the requirements of a time continuous quantum measurement. We find that for pure dephasing of an N -level system the additional degrees of freedom do lead to a time continuous quantum measure- ment even beyond the white noise limit. As an example we elaborate the case of Ornstein-Uhlenbeck noise.

Q 8.2 Mon 14:15 e001

Bohmian trajectories in a double slit - delayed choice analysis with entangled photons — •Jan Dziewior[1,2,3], Lukas Knips[1,2,3], Jasmin D. A. Meinecke[1,2,3], Maria Galli[4], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]MCQST, Munich, Germany — [4]Institut für Experimentalphysik, Innsbruck, Austria

Bohmian mechanics, a realistic interpretation of quantum mechanics, ascribes reality to the positions and momenta of quantum particles at the cost of a non-local ontology. Thus, contrary to standard quantum mechanics it allows to conceive of definite particle trajectories, while being fully compatible with the standard theory in all empirical predictions. Nevertheless, the plausibility of the Bohmian picture has been frequently put into question, most prominently with a Gedankenexperiment by Englert et al.

Here, the experimental realization of this Gedankenexperiment is presented. The conditions for the occurrence of so called "surrealistic" trajectories are realized by using a pair of entangled photons, where one of the photons is sent into an optical double slit. The average trajectories are recorded using a method inspired by the weak measurement concept. By detecting the second photon before or after the first photon passed the double slit, or even after the first photon was detected, it is possible to realize a series of delayed choice scenarios, exposing the differences in the conclusions of standard and Bohmian quantum mechanics.

Q 8.3 Mon 14:30 e001

Complementarity between one- and two-body visibilities — •Christoph Dittel[1] and Gregor Weihs[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

It has been shown for the separate (i.e. local) evolution of two entangled particles that the usual single-particle visibility is complementary to a two-body visibility built on the optimization of two-body correlators. Here we go one step further and generalize these concepts for common (i.e. global) evolutions of the two-body system. We identify two distinct two-body visibilities which both are complementary to the usual one-body interference visibility. Moreover, we show that only one of them satisfies the standard inequality associated with complementarity, while the other one entails an inequality with reversed direction. This, however, can be understood in terms of entanglement between the constituents.

Q 8.4 Mon 14:45 e001

Representing an experimental two photon state with a neural network — •Marcel Neugebauer[1], Martin Gärttner[2], Laurin Fischer[1], Alexander Jäger[1], Selim Jochim[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg — [2]Kirchhoff-Institut für Physik, Universität Heidelberg

Neural networks are mathematical models on which parameter optimization can be done in an efficient way, so that immense numbers of parameters can be handled. High dimensional optimization is also crucial to solve important problems in many body quantum physics. In particular quantum state tomography is a problem that scales exponentially in the measurement cost and in numerical optimization cost. New approaches to tackle this via the neural network representation of quantum states emerged recently. In this talk an ansatz is discussed in which a probability distribution over an informationally complete measurement is represented with a restricted Boltzmann machine. We represent the quantum state of a twin photon source with this technique and test its prediction capabilities against predictions of a maximum likelihood density matrix and actual measurement.

Q 8.5 Mon 15:00 e001

Detecting entanglement with two product observables — •Nikolai Wyderka[1], Mariami Gachechiladze[2], and Otfried Gühne[1] — [1]Naturwissenschaftlich Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany — [2]Institut für Theoretische Physik, Universität zu Köln

Entanglement is one of the most important features of quantum mechanics and is a key ingredient for applications in quantum cryptography, quantum computing and quantum metrology. As such, the experimental verification of entanglement is a necessary, yet challenging task. It is therefore of interest to find a way of detecting entanglement with as little effort as possible.

In this talk, we consider the case of bipartite systems and the measurement of two product observables. We find necessary and sufficient conditions for these observables to be able to detect entanglement in qubit-qubit and qubit-qutrit systems, and show that the same conditions fail for larger-dimensional systems.

Q 8.6 Mon 15:15 e001

Quantum tetrachotomous states in phase space — •Namrata Shukla[1], Naeem Akhtar[2], and Barry C. Sanders[2,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]University of Science and Technology, Shanghai, China — [3]Institute for Quantum Science and Technology, University of Calgary, Calgary, Canada

The well-studied quantum optical Schrödinger's cat state is a superposition of two distinguishable states, with quantum coherence between these macroscopically distinguishable states being of foundational and, in the context of quantum-information processing, practical use. We refer to these quantum-optical cat states as quantum dichotomous states, reflecting that the state is a superposition of two options, and we introduce the term quantum multichotomous state to refer to a superposition of multiple macroscopically distinguishable options. For a single degree of freedom, such as position, we construct the quantum multichotomous states as a superposition of Gaussian states on the position line in phase space. Using this nomenclature, a quantum tetrachotomous state (QTS) is a coherent superposition of four macroscopically distinguishable states. We define, analyze, and show how to create such states, and our focus on the QTSs is due to their exhibition of much richer phenomena than for the quantum dichotomous states. Our characterization of the QTS involves the Wigner function, its marginal distributions, and the photon-number distribution, and we discuss the QTS's approximate realization in a multiple-coupled-well system.

Q 8.7 Mon 15:30 e001

The shape of higher-dimensional state space – Bloch sphere analog for a qutrit — Christopher Eltschka[1], Marcus Huber[2], Simon Morelli[2], and •Jens Siewert[3,4] — [1]University of Regensburg, 93053 Regensburg, Germany — [2]IQOQI Vienna, Austrian Academy of Sciences, 1090 Vienna, Austria — [3]University of the Basque Country UPV/EHU, 48080 Bilbao, Spain — [4]IKERBASQUE Basque Foundation for Science, 48013 Bilbao, Spain

The Bloch sphere as a geometric representation of the state space for qubits is an ubiquitous tool to gain deeper insight and intuitive understanding of quantum-mechanical phenomena. Unfortunately, even for the next more complex system, the qutrit, such a geometric representation (rather than cross sections or projections) is not known. This is difficult because, in order to serve as a model for the state space, it should display a number of desirable properties, such as different surface parts corresponding to pure or mixed states, convexity, insphere and outsphere with the corresponding radii, pure states should form a connected set, etc. [1]. We show that, based on the Bloch representation of qutrit states, such a model can be constructed that captures many of the geometric features discussed in Ref. [1].

[1] I. Bengtsson, S. Weis, K. Zyczkowski, Geometry of the Set of Mixed Quantum States: An Apophatic Approach. In: P. Kielanowski et al (eds) Geometric Methods in Physics. Trends in Mathematics. Birkhäuser, Basel, 2013.

Q 8.8 Mon 15:45 e001

Representing quantum states on neuromorphic hardware — •Julius Vernie[1], Marcel Neugebauer[1], Laurin Fischer[1], Andreas Baumbach[2], Martin Gärttner[2], Selim Jochim[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

Artificial Neural Networks have already successfully been used to reproduce the results of quantum mechanical experiments. Spiking Neural Networks are now offering a promising new approach in this field. Especially, they can be implemented physically in the form of neuromorphic hardware, which leads to a great increase of computation speed compared to emulations on classical hardware. In our current work, we are training a neuromorphic computer to reproduce the results of quantum mechanical experiments and looking for new ways to encode quantum information, leading to more efficient predictions for complex quantum systems.

Q 9: Quantum gases (Bosons) I

Time: Monday 14:00–16:00 Location: e214

Invited Talk Q 9.1 Mon 14:00 e214

Critical dynamics and prethermalization in lattice gauge theories — •Jad Halimeh[1,2,3] and Philipp Hauke[1,2,3] — [1]Kirchhoff Institute for Physics, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institute for Theoretical Physics, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]Department of Physics, University of Trento, Via Sommarive 14, 38123 Povo (TN), Italy

Local gauge invariance is always violated to some extent in quantum simulation experiments. A rigorous understanding of gauge-invariance violation and how to protect against it are thus of paramount importance. We present analytic and numerical results showing that gauge-invariance violation in a quantum simulator resulting from inherent gauge-noninvariant processes grow only perturbatively at short times, before entering long-lived prethermal plateaus, and eventually settling at long times into an equal admixture of all gauge-invariant sectors of the system. An energy constraint penalizing terms driving the system away from the initial gauge-invariant sector suppresses the violation up to infinite times. In congruence with our numerical results that show that this suppression is independent of system size, we argue analytically why this suppression will hold even in the thermodynamic limit. Finally, we present experimental results for the quantum simulation of a U(1) quantum link model mapping on a single-species bosonic lattice, where we sweep through a quantum phase transition and certify the emergent gauge-invariant dynamics.

Q 9.2 Mon 14:30 e214

Anomalous Floquet topological phases in periodically-driven hexagonal lattices — •Karen Wintersperger[1,2], Christoph Braun[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstraße 4, 80799 München — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Ultracold atoms in periodically-driven optical lattices can be used to simulate systems with nontrivial topological properties. Due to the periodic driving, energy conservation is relaxed which makes it possible to realize systems with properties that go beyond those of conventional static systems. For instance, chiral edge modes can exist even if the bulk is topologically trivial [1].

We study such anomalous Floquet phases experimentally using a BEC of K39 in an optical honeycomb lattice with periodically modulated tunnel couplings. By monitoring the closing and reopening of energy gaps in the band structure we are able to track the transitions between different Floquet phases. Moreover, we probe the topological porperties of the bulk by measuring the Hall deflection induced by local changes in the Berry curvature. Combining these measurements enables us to extract the topological invariants of the bulk bands and the energy gaps, which are both required to accurately classify the topological phases of Floquet systems [2, 3].

[1] T. Kitagawa et al., Phys. Rev. B 82, 235114 (2010) [2] M. Rudner et al., PRX 3, 031005 (2013) [3] N. Ünal et al., PRL 122, 253601 (2019)

Q 9.3 Mon 14:45 e214

Floquet-Induced Superfluidity with Periodically Modulated Interactions of Two-Species Hardcore Bosons in a One-dimensional Optical Lattice — Tao Wang[1], Shijie Hu[2], Sebastian Eggert[2], Michael Fleischhauer[2], •Axel Pelster[2], and Xue-Feng Zhang[3] — [1]Hubei Key Laboratory of Optical Information and Pattern Recognition, Wuhan Institute of Technology, China — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [3]Department of Physics, Chongqing University, China

We consider two species of hard-core bosons with density dependent hopping in a one-dimensional optical lattice, for which we propose experimental realizations using time-periodic driving. The quantum phase diagram for half-integer filling is determined by combining different advanced numerical simulations with analytic calculations. We find that a reduction of the density-dependent hopping induces a Mott-insulator to superfluid transition. For negative hopping a previously unknown state is found, where one species induces a gauge phase of the other species, which leads to a superfluid phase of gauge-paired particles. The corresponding experimental signatures are discussed.

Q 9.4 Mon 15:00 e214

Scaling analysis of localization effects in the disordered two-dimensional Bose-Hubbard-model — •Andreas Geissler[1,2] and Guido Pupillo[1,3] — [1]ISIS, University of Strasbourg, Strasbourg, France — [2]Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, Germany — [3]IPCMS, University of Strasbourg, Strasbourg, France

Recent experiments have shown signatures of many-body localization (MBL) in the disordered Bose-Hubbard model in one and two dimensional ultra cold atomic lattice gases [1] as well as the related superfluid to Bose-glass transition in three dimensions [2]. A proper theoretical understanding of the MBL phenomenon depends on knowledge about the full eigenstate spectrum. Therefore, exact numerical studies have been limited to small system sizes. In contrast, the Bose-glass phase can already be understood via the ground state. So, by applying the fluctuation operator expansion method [3] to obtain beyond mean-field insight into the full fluctuation spectrum, we have performed a scaling analysis of both phenomena within a single framework. With the collection of obtained critical points, we are able to map out a phase diagram showing no direct superfluid to fully localized transition due to the intermediate Bose-glass phase. We further discuss the scaling of correlations for various quenches.

[1] C. D'Errico et al., PRL 113, 095301 (2014); J.-y. Choi et al., Science 352, 1547 (2016)

[2] C. Meldgin et al., Nature Physics 12, 646 (2016)

[3] A. Geissler et al., PRA 98, 063635 (2018)

Q 9.5 Mon 15:15 e214

Eigenstate versus Spectral Structure of Interacting Bosons on a Lattice — •Lukas Pausch[1], Edoardo Carnio[1], Alberto Rodríguez[1,2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Departamento de Física Fundamental, Universidad de Salamanca, Plaza de la Merced, E-37008 Salamanca, Spain

We study the transition from regular to chaotic spectral and eigenvector structure in the Bose-Hubbard Hamiltonian. Using the framework of generalized fractal dimensions to characterize the eigenstates' localisation properties in Fock space, we show that the change of the latter with the ratio of tunneling to interaction strength correlates with a qualitative change of the energy level statistics: In the regime of fully developed spectral chaos each individual eigenstate delocalizes over the entire Fock basis. This is corroborated by a very narrow distribution of generalized fractal dimensions, which becomes ever sharper as the Hilbert space dimension is increased.

Q 9.6 Mon 15:30 e214

Macroscopic boundary effects in the one-dimensional extended Bose-Hubbard model — •Sebastian Stumper, Junichi Okamoto, and Michael Thoss — Insitute of Physics, University of Freiburg, Freiburg, Germany

We study the effect of different open boundary conditions on the insulating ground states of the one-dimensional extended Bose-Hubbard model at and near unit filling. To this end, we employ the density matrix renormalization group method. To characterize the system, various order parameters and entanglement entropies are calculated. When opposite edge potentials are added to the two ends of the chain, the inversion symmetry is explicitly broken, and the bulk phases appear. On the other hand, simple open boundary conditions often exhibit non-degenerate ground states with a domain wall in the middle of the chain, which induces a sign-flip of an order parameter. Such a domain wall can lead to an algebraic behavior of the off-diagonals of the single particle density matrix. We show that this algebraic behavior adds only a finite contribution to the entanglement entropy, which does not diverge as the system size increases. Therefore, it is not an indication of a superfluid phase. We confirm this picture by analytical calculations based on an effective Hamiltonian for a domain wall.

Q 9.7 Mon 15:45 e214

Superfluid phases of dipolar gases in low dimensions — •Rebecca Kraus[1], Krzysztof Biedroń[2], Jakub Zakrzewski[2,3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Instytut Fizyki imienia Mariana Smoluchowskiego, Uniwersytet Jagielloński, Łojasiewicza 11, 30-048 Kraków, Poland — [3]Mark Kac Complex Systems Research Center, Jagiellonian University, Łojasiewicza 11, 30-348 Kraków, Poland

We determine the quantum ground state of ultracold dipolar bosons by means of DMRG. The bosons are confined in an optical lattice in a quasi-one dimensional geometry, their dynamics is modeled by an extended Bose-Hubbard model whose terms and coefficients account for the power-law decay of the dipolar potential and of its spatial anisotropy. We show that the dipolar interactions give rise to superfluid phases at vanishing kinetic energies, which exhibit a site-dependent phase. We characterize these phases as a function of the Bose-Hubbard parameters and analyse the entanglement entropy as a function of the strength of the dipolar interactions.

Q 10: Ultra-cold atoms, ions, and BEC II (joint session A/Q)

Time: Monday 14:00–16:00 Location: f303

Invited Talk Q 10.1 Mon 14:00 f303

Reducing their complexity and miniaturise BEC interferometers — •Waldemar Herr[1], Hendrik Heine[1], Alexander Kassner[2], Christoph Künzler[2], Marc C. Wurz[2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover, Germany — [2]Institut für Mikroproduktionstechnik, Leibniz Universität, Hannover

Matterwave interferometry with Bose Einstein Condensates (BEC) promises exciting prospects in inertial sensing and research on fundamental physics both on ground and in space. By now, we can create BECs very efficiently by using atom chips and compact realisations have already been shown, e.g. by creating the first BEC in space on a sounding rocket mission. However, for in-field or satellite-borne applications, it is vital to further reduce the complexity in order to lower size, weight and power demands and to transform BEC interferometers to easy-to-use devices.

In this talk, different aspects ranging from interferometry schemes, sensor fusion concepts and results on a magneto optical trap and sub-Doppler cooling using only a single beam of light in combination with an optical grating on an atom chip will be discussed.

Q 10.2 Mon 14:30 f303

Quantum fluctuations and uncertainty relations in NLS solitons and breathers — •Oleksandr Marchukov[1,2], Boris Malomed[2], Maxim Olshanii[3], Vanja Dunjko[3], Randall Hulet[4], and Vladimir Yurovsky[2] — [1]Technische Universität Darmstadt, Darmstadt, Germany — [2]Tel Aviv University, Tel Aviv-Yaffo, Israel — [3]University of Massachusetts Boston, Boston, MA, USA — [4]Rice University, Houston, TX, USA

We consider the quantum fluctuations of the macroscopic variables associated with a breather, a second-order soliton solution of nonlinear Schrödinger equation. Linearizing the evolution of the bosonic quantum field around the Bose condensate in a breather state, we express the quantum fluctuations of the macroscopic variables through the fluctuations of the full quantum field. We compare two models for the state of the quantum field of fluctuations surrounding the classical field of the Bose-Einstein condensate: a conventionally used, computationally convenient "white noise", and a correlated noise which assumes that the breather has been created from a fundamental soliton, by means of the application of the factor-of-four quench of the nonlinearity strength. We evaluate the initial quantum uncertainties of the macroscopic parameters and their time evolution. This approach is well suited for the description of Bose gas with large number of atoms and suggests the possibility for experimental observation of macroscopic quantum fluctuations.

Q 10.3 Mon 14:45 f303

Rogue waves in a selfgravitating BEC — •Sandro Gödtel[1], Claus Lämmerzahl[1], and Domenico Giulini[1,2] — [1]ZARM, University of Bremen, Germany — [2]ITP, Leibniz University Hannover, Germany

The coupling between gravity and quantum mechanics is still an open question in physics. For this, we investigate an approach to increase possible gravitational effects within a quantum system such as a Bose-Einstein condensate. We show that the theoretical description by the well-known Gross-Pitaevskii equation leads to an interesting nonlinear phenomenon, namely rogue waves. Originally observed in ocean waves these waves locally increase the density and are often modeled by the Peregrine soliton or the so called multi-rogue wave solutions. By including a gravitational self-interaction we estimate the impact on the condensate with typical experimental values and specify the regime where it may become significant and observable.

Q 10.4 Mon 15:00 f303

Guided Atom Interferometry with Bose-Einstein Condensates in Painted Optical Potentials — •Sebastian Bode, Knut Stolzenberg, Alexander Herbst, Henning Albers, Ernst M. Rasel, and Dennis Schlippert — Institute of Quantum Optics - Leibniz University Hannover

Inertial navigation allows for the positioning in space diminishing the dependency on global navigation satellite systems. Guided atom interferometers are a candidate for compact inertial measurement units with outstanding accuracy and stability in harsh environments.

We utilize a 2D-acousto-optic deflector (AOD) in the beam path of an optical dipole trap in combination with a software defined radio (SDR) RF-source for the creation of time-dependent arbitrary potentials. The experimental setup facilitates the creation of ^{87}Rb BECs with large atom numbers and subsequent guided atom interferometry. For the splitting, holding, and recombination of the atom cloud during the interferometric sequence the confining potential is modified resulting in multiple distinct potential minima with well defined atom populations. We report on first results in absolute and differential measurements and discuss various future configurations.

This work is funded by the Federal Ministry of Education and Research (BMBF) through the funding program Photonics Research Germany (contract number 13N14875), and the DFG under Germany*s Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 10.5 Mon 15:15 f303

Josephson effects in coupled anisotropic Bose-Einstein condensates — •Marc Momme, Yuriy Bidasyuk, and Michael Weyrauch — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Josephson effects can manifest in a bose-condensed atomic gas with two components, if the phase of both components remains (mostly) coherent. That way, many experimental and theoretical studies of bosonic Josephson effects have been conducted to gain insight about the nature of macroscopic quantum coherence. The common theoretical description for such systems is the two-mode model, which relies on the assumption that the coupling between two components is much weaker then the energy required to create excitations inside each condensate. However if the Josephson oscillations couple with the longitudinal modes of the trap, the two-mode approximation is no longer valid.

The present study focuses on one system where such a coupling can occur: the bosonic equivalent of a long Josephson junction. Thereby a BEC is put in a cigar-shaped trap with the barrier parallel to the long axis of the trap. Effectively, two coupled quasi one-dimensional condensates are formed. We compare the results of mean-field numerical simulations with predictions of simplified effective models. We show how collective excitations influence the population dynamics of the condensates.

Q 10.6 Mon 15:30 f303

Josephson junction dynamics in an ultracold two-dimensional Bose gas — •Vijay Singh and Ludwig Mathey — Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany

We investigate the Berezinskii-Kosterlitz-Thouless (BKT) scaling of the critical current of Josephson junction dynamics across a barrier potential in a two-dimensional (2D) Bose gas, motivated by recent experiments by Luick *et al.* arXiv:1908.09776. Using classical-field dynamics, we determine the dynamical regimes of this system, as a function of temperature and barrier height. As a central observable we determine the current-phase relation, as a defining property of these regimes. In addition to the ideal junction regime, we find a multimode regime, a second-harmonic regime, and an overdamped regime. For the ideal junction regime, we derive an analytical estimate for the critical current, which predicts the BKT scaling. We demonstrate this scaling behavior numerically for varying system sizes. The estimates of the critical current show excellent agreement to the numerical simulations and the experiments. Furthermore, we show the damping of the supercurrent due to phonon excitations in the bulk, and the nucleation of vortex-antivortex pairs in the junction.

Q 10.7 Mon 15:45 f303

Dynamical control of conductivity in a bosonic Josephson junction — •Beilei Zhu[1], Vijay Pal Singh[1], Junichi Okamoto[2], and Ludwig Mathey[1,3] — [1]Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, Hamburg, Germany — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

We propose to demonstrate dynamical enhancement of conductivity in a bosonic Josephson junction composed of two weakly coupled one dimensional condensates. A current is induced by a periodically modulated potential difference between the condensates, giving access to conductivity of the junction. We propose to control the conductivity via parametric driving of the tunneling energy. We demonstrate that the low frequency conductivity of the junction can be enhanced or suppressed, depending on the choice of the driving frequency. The experimental realization of this proposal constitutes a quantum simulation of recently proposed mechanism for optically induced superconductivity in pump-probe experiments.

Q 11: Quantum Optics I

Time: Monday 14:00–16:00 Location: f342

Q 11.1 Mon 14:00 f342

Super-resolution imaging of a single atom: the role of orbital angular momentum — •Martin Drechsler[1,2], Sebastian Wolf[1], Elias Alstead[1], Ferdinand Schmidt-Kaler[1], and Christian Schmiegelow[2] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz — [2]Departamento de Física, FCEyN, UBA and IFIBA, UBA CONICET

Cold trapped ions are one of the most precise platforms to probe light matter interaction, due to the high level of control and isolation from the environment. Recently, it was shown that by using beams with orbital angular momentum, quadrupole transitions of a single ^{40}Ca^{+} ion can be excited when placing the ion in places where the light intensity vanishes [1, 2]. In this work, we present a method to take advantage of this effect to perform an analogous of Stimulated Emission Depletion Microscopy (STED) [3] to image the wave function of a single trapped ion.

[1] Schmiegelow, C. T., Schulz, J., Kaufmann, H., Ruster, T., Poschinger, U. G., Schmidt-Kaler, F. (2016). *Transfer of optical orbital angular momentum to a bound electron.* Nature communications, 7, 12998.

[2] Quinteiro, G. F., Schmidt-Kaler, F., Schmiegelow, C. T. (2017). *Twisted-light ion interaction: the role of longitudinal fields.* Phys. Rev. Lett., 119(25), 253203.

[3] Hell, S. W. (2003). *Toward fluorescence nanoscopy.* Nature biotechnology, 21(11), 1347.

Q 11.2 Mon 14:15 f342

Spectral properties of single photons from a single $^{40}Ca^{+}$ ion
— Matthias Kreis, •Omar Elshehy, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Single photons with well-controlled spectral and temporal properties are an essential resource for optical quantum communication protocols such as quantum repeaters.

We investigate single photons at 393 nm wavelength generated from a single $^{40}Ca^{+}$-ion by a controlled Raman scattering process in the Λ-shaped 3-level configuration consisting of the $D_{5/2}(m = -5/2)$, $P_{3/2}(m = -3/2)$, and $S_{1/2}(m = -1/2)$ Zeeman levels.

The spectral properties of the Raman photons are analyzed by a 396 mm long scanning Fabry-Perot cavity with 1 MHz transmission bandwidth stabilized to a 393 nm reference laser. Spectra are taken for various values of Rabi frequencyy and detuning of the 854 nm driving laser, and compared to calculated spectra, following the theory in [1].

[1] P. Müller et al., Phys. Rev. A **96**, 023861 (2017).

Q 11.3 Mon 14:30 f342

Coherent and incoherent many-particle interference tests of Born's rule
— •Marc-Oliver Pleinert[1,2], Eric Lutz[3], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91052 Erlangen, Germany — [3]Institute for Theoretical Physics I, University of Stuttgart, D-70550 Stuttgart, Germany

Quantum mechanics is based on a set of only a few postulates, which can be separated into two parts: one part governing the 'inner' structure, i.e., the definition and dynamics of the state space, the wave function and the observables; and one part making the connection to experiments ('external' world). Here, we focus on the second part, in particular Born's rule, which - simply put - relates detection probabilities to the modulus square of the wave function. Born's rule can be tested in interference experiments, where the configuration of possible paths can be precisely controlled and compared. In such experiments, according to Born's rule, M-particle correlations of mutually coherent sources (MCS) are limited to order 2M, while M-particle correlations of mutually incoherent sources (MIS) are limited to order M. Excluding any higher-order correlations is hence a direct test of Born's rule and thus quantum mechanics itself. We demonstrate the vanishing of such higher-order terms in two-particle experiments for MCS and in two-, three-, and four-particle experiments for MIS.

Q 11.4 Mon 14:45 f342

Spatial entanglement and state engineering via four-photon Hong-Ou-Mandel interference
— •Alessandro Ferreri, Vahid Ansari, Christine Silberhorn, and Polina Sharapova — University of Paderborn, Paderborn, Germany

Entangled photon states are fundamental element of quantum information and quantum communication processes. For the current state-of-the-art of optical -based technologies, the investigation of highly entangled systems, characterized by a large number of photons, is extremely important.

In this work we have investigated and maximized the degree of spatial entanglement in a spatially bipartite optical system characterized by four photons based on Hong-Ou-Mandel interference with four photons. The four photons are created by a single type-II parametric down-conversion source. With the use of such device and a proper choice of parameters, we have observed an antibunching behaviour as well as fast structured oscillations with a period of the pump wavelength in the coincidence probability. These features of the coincidence probability indicate spatial entanglement. We can modify the structure of such oscillations by varying the mode structure. Furthermore, by opportunely varying the parameters of our device, we can generate different combination of the four-dimensional Bell states. Finally, a small modification of our device allows to generate fringe pattern with smaller periodicity than the pump wavelength, that can be used to increase the sensitivity of measurement.

Q 11.5 Mon 15:00 f342

Witnessing non-classicality through large deviations in quantum optics
— •Dario Cilluffo[1,2,3,4], Giuseppe Buonaiuto[3,4,5], Salvatore Lorenzo[1], Gioacchino Massimo Palma[1,2], Francesco Ciccarello[1,2], Federico Carollo[3,4], and Igor Lesanovsky[3,4,5] — [1]Università degli Studi di Palermo, Dipartimento di Fisica e Chimica - Emilio Segrè, via Archirafi 36, I-90123 Palermo, Italy — [2]NEST, Istituto Nanoscienze-CNR, Piazza S. Silvestro 12, 56127 Pisa, Italy — [3]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [4]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [5]Institut fuer Theoretische Physik, Universitaet Tuebingen, Auf der Morgenstelle 14, 72076 Tuebingen, Germany

Non-classical correlations in quantum optics as resources for quantum computation are important in the quest for highly-specialized quantum devices. The standard way to investigate such effects relies on either the characterization of the inherent features of sources and circuits or the study of the output radiation of a given optical setup. In this work we provide a natural link between the two frameworks by exploiting the thermodynamics of quantum trajectories. This procedure enables investigation of the quantum properties of the photon fields from a generic source via the analysis of the fluctuations and correlations of time-integrated quantities associated with the photon counting of the emitted light.

Q 11.6 Mon 15:15 f342

Using a genuine local oscillator for direct sampling of the Wigner function
— •Johannes Tiedau[1], Christof Eigner[1], Victor Quiring[1], Laura Padberg[1], Raimund Ricken[1], Benjamin Brecht[1], Tim J. Bartley[2], and Christine Silberhorn[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]Universität Paderborn, Mesoskopische Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Local oscillators are essential for quantum state characterisation and many encoding schemes in long-distance communication since they offer mode-selective and phase-sensitive measurements. Despite their name, typical experimental implementations of "local" oscillators in homodyne detection are directly derived from the laser source which generates the states, thereby opening security loopholes in quantum communication and information processing protocols. Here, we demonstrate an approach based on a genuinely local oscillator, which is generated at the receiver and hence does not suffer from this loophole. In order to show full control over our local oscillator we investigate a phase-sensitive two-mode squeezed vacuum state. Instead of standard strong field homodyning, we directly sample the Wigner function by phase-resolved photon counting. We show that this method is, in the strong squeezing regime, robust to a larger phase-jitter than standard homodyne detection.

Q 11.7 Mon 15:30 f342

Spectral properties of the cavity-enhanced spontaneous parametric down-conversion below the cavity threshold
— •Golnoush Shafiee[1,2], Dmitry V. Strekalov[1], Alexander Otterpohl[1,2,3], Florian Sedlmeir[1], Gerhard Schunk[1], Ulrich Vogl[1], Harald G.L. Schwefel[4], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, Friedrich-Alexander University Erlangen-Nuremberg, Germany — [3]Erlangen Graduate School in Advanced Optical Technologies, Friedrich-Alexander University Erlangen-Nuremberg, Germany — [4]The Dodd-Walls Centre for Photonic and Quantum Technologies, Dunedin, New Zealand

Single photons and photon pairs are an important resource for quantum information processing. This motivated a thorough study of the spectral and temporal properties of parametric light, both above and below the Optical Parametric Oscillator (OPO) threshold. The pursuit of a higher two-photon emission rate leads into an intermediate regime where the OPO still operates below the threshold but the nonlinear cavity phenomena cannot be neglected anymore. Here, we investigate the properties of the down-converted photons from a whispering gallery resonator, using correlation measurements, from far below the threshold to close enough to the OPO threshold such that stimulated processes already become important

Q 11.8 Mon 15:45 f342

Signatures of photon-photon scattering in Hermite-Gaussian beams
— •Ricardo R.Q.P.T. Oude Weernink[1,2] and Felix Karbstein[1,2] — [1]Helmholtz-Institut Jena, 07743 Jena, Germany — [2]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany

Quantum electrodynamics predicts effective nonlinear interactions between electromagnetic fields mediated by quantum vacuum fluctuations, a prominent example being photon-photon scattering. Measuring this process directly in an experiment is a difficult endeavour and has yet to be achieved. One of the toughest challenges for any experimental approach is to find scenarios allowing for a clear signal-to-background separation.

In this talk we present the following set-up: We focus on the geometrically simple scenario of two counter-propagating high-intensity laser beams, though allow them to be prepared in arbitrary Hermite-Gaussian modes or superpositions thereof. We are mainly interested in ways to enhance the discernible signal, but also study the behaviour of the signal photon number for non-optimal collisions with finite impact parameter.

Q 12: Quantum Effects

Time: Monday 14:00–16:00 Location: f442

Q 12.1 Mon 14:00 f442

Exploring complex graphs using 3D quantum walks of correlated photon pairs — •Max Ehrhardt[1], Robert Keil[2], Lukas Maczewsky[1], Matthias Heinrich[1], and Alexander Szameit[1] — [1]Institut für Physik, Universität Rostock, Albert-Einstein-Str. 23-24, 18059 Rostock, Germany — [2]Universität Innsbruck, Institut für Experimentalphysik, Technikerstr. 25d, 6020 Innsbruck, Austria

The complexity of graphs fundamentally constrains the applicative potential of quantum walks in quantum search algorithms, as well as the study of graph theory problems and biochemical energy transport. Currently, the experimental implementation of such graphs is limited to two dimensions for more than a single walker. We harness the hybrid interaction of spatial degrees of freedom and coupling between the polarization states of single photons to implement quantum walks on 3D graphs in waveguide circuits for the first time. In order to illustrate the functional capabilities of our approach, we demonstrate that polarization forms a synthetic space in a single waveguide, and successively upgrade this system to the third dimension. In addition to experimentally exploring 3D graphs with two correlated photons, we also present a new approach to the implementation of negative coupling coefficients as well as the observation of fermionic statistics with two bosonic quantum walkers.

Q 12.2 Mon 14:15 f442

Partial distinguishability in systems of identical particles — •Gabriel Dufour, Eric Brunner, Christoph Dittel, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

A complete description of bosonic and fermionic many-body systems should include degrees of freedom which could, in principle, allow to distinguish the particles. Indeed, the existence of such "labels" leads to the degradation of many-particle interference in the dynamical degrees of freedom. We show how partial distinguishability can be described in terms of entanglement between dynamical and label degrees of freedom and relate the coherences of the reduced state of the dynamical degrees of freedom with the interference contributions to expectation values of many-body observables.

Q 12.3 Mon 14:30 f442

Are photons really bosons? — •Chris Müller[1], Konrad Tschernig[2], Malte Smoor[1], Tim Kroh[1], Armando Perez-Leija[2], Kurt Busch[1,2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, Germany — [2]Max-Born-Institut, Germany

Quantum electrodynamics introduces photons as bosons, that means their joint wavefunction is symmetric under particle exchange. So far the bosonic nature of photons has been demonstrated only indirectly, e.g. by observing photon bunching in the Hong-Ou-Mandel effect [1]. It would be highly interesting to measure the exchange phase ϕ directly, which should be zero for bosons and π for fermions. Another possibility is the exotic anyon, where the exchange phase can have values different from 0 or π. Protocols for measuring the exchange phase using massive particles, have been recently proposed [3].

Here, we present a novel joint theoretical and experimental approach to measure the exchange phase of photons directly. Our setup consists of two coupled Mach-Zehnder interferometers fed by indistinguishable photon pairs generated in a cavity-enhanced parametric down-conversion source [4]. We will show our first results of measuring the exchange phase of photons and discuss the sensitivity for potential deviations from the expected value of zero.

[1] C. K. Hong et al., Physical Review Letters 59, 2044, 1987
[2] C. F. Roos et al., Physical Review Letters 119, 160401, 2017
[3] A. Ahlrichs et al., Applied Physics Letter 108, 021111, 2016

Q 12.4 Mon 14:45 f442

Extracting particle distinguishability from imperfect suppressions in many-particle interference — •Michael Minke, Christoph Dittel, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder Str. 3, 79104 Freiburg, Federal Republic of Germany

The Deviations from perfect suppression of the coincident output event in the two-particle Hong-Ou-Mandel experiment are indicative of some degree of mutual distinguishability between both particles. While Hong-Ou-Mandel-type suppression has been generalised to many perfectly indistinguishable particles, it remained unknown to date whether finite detection probabilities of output events which are suppressed in an ideal scenario likewise reveal information on the particles' distinguishability. Here we show that, in the evolution of four partially distinguishable particles on the two dimensional hypercube graph (or on a four-mode Sylvester interferometer), violations of suppression laws allow us to draw conclusions on the mutual distinguishability of all four constituents.

Q 12.5 Mon 15:00 f442

Quantum light: wave or particle? — •Syamsundar De, Jan Sperling, Thomas Nitsche, Johannes Tiedau, Sonja Barkhofen, Benjamin Brecht, and Christine Silberhorn — Integrated Quantum Optics, Paderborn University, Warburger Strasse 100, 33098 Paderborn, Germany

Wave-particle dualism is commonly interpreted as that the quantum objects exhibit either particle- or wave-like behavior. In this study, we challenge this usual notion of wave-particle duality by experimentally showing that neither the wave nor the particle picture can successfully describe our observations. We introduce correlation-based criteria that allow us to simultaneously and quantitatively assess wave and particle properties. It turns out that the measured correlations in our experiment using squeezed light are indeed incompatible with the predictions for waves and particles, simultaneously falsifying these two classical notions in a single quantum system. Besides, we establish a connection between our correlation-based criteria with the complementary notions of quantum coherence, linked with either the quantum-optical nonclassicality or the encoding capability of quantum information in particles. Additionally, we apply our methodology to certify the nonclassicality of coherent states, which are traditionally treated as classical light.

Q 12.6 Mon 15:15 f442

Biphoton interference of terahertz and visible light — •Mirco Kutas[1,2], Björn Haase[1,2], Patricia Bickert[1], Felix Riexinger[1,2], Daniel Molter[1], and Georg von Freymann[1,2] — [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

We present our latest developments in the detection of terahertz radiation using visible light [Kutas *et al.*, arXiv:1909.06855, (2019)]. It bases on a quantum optical technique to detect radiation by transferring photon properties via biphoton correlation into another and better detectable spectral range [Lemos *et al.*, *Nature* **512**, 409-412 (2014)]. Only one photon of a correlated pair interacts with the sample, whereas solely its associated partner is detected, having never interacted with the sample. This concept is especially interesting for terahertz radiation, as detection in this frequency range is still technically complex. In our experiments the correlated photon pairs are created in a nonlinear crystal either due to spontaneous parametric down-conversion or conversion of thermal photons [Haase *et al.*, Opt. Express **27**, 7458-

7468 (2019)]. Detecting the interference of the visible photons, we are able to perform layer thickness measurements with terahertz radiation.

Q 12.7 Mon 15:30 f442

Nonlinear terahertz interferometry with visible photons — •Björn Haase[1,2], Mirco Kutas[1,2], Felix Riexinger[1,2], Patricia Bickert[1], Daniel Molter[1], and Georg von Freymann[1,2] — [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

Nowadays, it is still technically challenging to detect terahertz radiation, although many different applications have been developed in the past. Based on the indistinguishability of correlated biphoton pairs, created by spontaneous parametric down-conversion (SPDC) due to vacuum fluctuations in a nonlinear crystal, Lemos *et al.* showed the possibility to transfer properties of photons in one spectral range into another range, for which better cameras exist [Lemos *et al.*, *Nature* **512**, 409-412, (2014)].

Recently, we demonstrated this concept in the strongly frequency non-degenerated regime with pairs of photons in the terahertz and visible spectral range [Kutas *et al.*, arXiv:1909.06855, (2019)]. This concept enables us to determine sample properties in the terahertz frequency range using cameras that are sensitive only for visible light. Inspired by these studies, we present results of an alternative approach of this concept, by seeding the nonlinear interaction with phase-unlocked pulsed terahertz photons [Haase *et al.*, 44$^{\text{th}}$ IRMMW-THz, Paris (2019)]. Because of an increased signal-to-noise ratio, this will facilitate us to reduce the required measurement time significantly.

Q 12.8 Mon 15:45 f442

A Compact Laser System for Quantum Gas Experiments in BECCAL on the ISS — •Victoria Henderson[1,2], Ahmad Bawamia[2], Jean-Pierre Marburger[3], André Wenzlawski[3], Andreas Wicht[2], Patrick Windpassinger[3], Markus Krutzik[1,2], Achim Peters[1,2], and The BECCAL Team[1,2,3,4,5,6,7] — [1]HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]JGU, Mainz — [4]LU Hannover — [5]ZARM, Bremen — [6]DLR, Bremen — [7]Universität Ulm

BECCAL (BEC - Cold Atom Laboratory) is a multi-user quantum gas experiment designed to be operated on the ISS. It is a collaboration between DLR and NASA, built upon a heritage of sounding rocket and drop tower experiments as well as NASA's Cold Atom Lab. It will enable the exploration of fundamental physics with Rb and K BECs in microgravity, facilitated by prolonged timescales and ultra-low energy scales compared to those achievable on Earth.

The ambitious functionality of BECCAL presents a unique challenge for laser system design, especially in terms of the stringent size weight and power limitations. To meet this we combine micro-integrated diode lasers (from FBH) with Zerodur boards of miniaturized free-space optics (from JGU), all connected via fibre optics. These technologies have proven their reliability in many qualification tests. We will present the current design of the BECCAL laser system, alongside the requirements, concepts and heritage that has formed it.

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 DLR50WP1702.

Q 13: Posters: Quantum Optics and Photonics I

Time: Monday 16:30–18:30 Location: Empore Lichthof

Q 13.1 Mon 16:30 Empore Lichthof

Orbital interaction in the second band of a bipartite optical lattice — •José Vargas, Carl Hippler, and Andreas Hemmerich — Universitaet Hamburg, Hamburg, Germany

We study the orbital interaction dynamics of atoms prepared in the second band of a bipartite square optical lattice. The interplay of band relaxation, condensate formation, and pair exchange dynamics between degenerate condensation points are explored.

Q 13.2 Mon 16:30 Empore Lichthof

A versatile quantum gas machine for the study of dynamics far from equilibrium — •Maurus Hans, Celia Viermann, Marius Sparn, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff- Institut für Physik, Universität Heidelberg, Deutschland

Well controlled experiments with degenerate quantum gases allow for the study of isolated many body systems and their dynamics far from equilibrium that are intractable in purely theoretical studies.

In harmonically trapped quasi one dimensional systems the emergence of universal dynamics has been experimentally observed [1,2]. Our next generation quantum gas setup aims at studying the influence of defects, finite size, dimensionality and interactions in this context. For versatility of the trap geometry and realizing homogeneous systems we implement a vertical pancake trap supplemented by a blue detuned vertical beam shaped by a digital micro-mirror device (DMD). We use 39K which features broad Feshbach resonances and allows for tuning of the interaction strength and quenches to bring the system out of equilibrium.

We give an overview of our setup, the route to BEC and the current status of the experiment.

[1] Prüfer, M. et al., Nature 563, 217-220 (2018) [2] Erne, S. et al., Nature 563, 225-229 (2018)

Q 13.3 Mon 16:30 Empore Lichthof

Weakly interacting Bose-Einstein condensates as quantum baths: (Pre)thermalization and nonequilibrium steady states — •Alexander Schnell and André Eckardt — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

Motivated by recent experimental progress [Phys. Rev. Lett. 121, 130403 (2018)], we study the dynamics of an ideal gas of bosonic impurity atoms which are weakly coupled to a weakly interacting background BEC. Using the standard open-quantum systems framework of Born-, Markov-, and rotating-wave approximation, we find a description of the impurity dynamics in terms of a Pauli rate equation. The rates have the typical structure of thermal rates for a (sub)ohmic bath with an additional factor that guarantees momentum conservation. For a free impurity atom with higher mass than the background atoms it was found [Phys. Rev. A 97, 023621 (2018)] that, due to momentum conservation, thermalization occurs only above a critical momentum. We find similar results for one or many impurity atoms that are additionally subjected to an optical lattice. We show that interesting nonequilibrium steady states can be engineered if the optical lattice is time-periodically driven.

Q 13.4 Mon 16:30 Empore Lichthof

Spinor BEC coupled to an optical cavity: from the Dicke model to spin textures and dissipation induced instabilities — •Nishant Dogra[1,2], Manuele Landini[1,3], Katrin Kroeger[1], Lorenz Hruby[1], Francesco Ferri[1], Rodrigo Rosa-Medina[1], Fabian Finger[1], Tobias Donner[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich, Switzerland — [2]Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [3]Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, 6020 Innsbruck, Austria

In the past decade, the driven-dissipative Dicke model has been realized and extensively studied by coupling a Bose-Einstein condensate (BEC) to an off-resonant laser field and a high-finesse optical cavity. In this poster, I will present our recent experimental results where we have extended this scheme to a spinor BEC allowing us to introduce strong opto-magnetical effects in the system and go beyond the Dicke model. Specifically, by starting with a mixture of two spin states, we identify two qualitatively new regimes. First, a spin texture with spatially modulated magnetization arises as a result of coherent opto-magnetic coupling in the system. Second, the dispersive effect of the resonator losses mediates a dissipative coupling in the system which results in a non-stationary state of chiral nature. Our system provides a model example where both coherent and dissipative regimes are independently realized and furthermore, the transition boundary between the two regimes can be explored.

Q 13.5 Mon 16:30 Empore Lichthof

A New Caesium Quantum Gas Microscope — •Hendrik von Raven[1,2,3], Till Klostermann[1,3], Jingjing Chen[1,3], Chris-

tian Schweizer[1,2,3], Cesar Cabrera[1,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,3] — [1]Ludwig-Maximilians Universität München, Schellingstr. 4, 80799 München, Germany — [2]Max Planck Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, Schellingstr. 4, 80799 München, Germany

Ultra cold atomic systems can be used to investigate topological quantum effects. So far, research has mainly focused on non-interacting systems. We are setting up a new experiment utilizing Caesium that aims to investigate many-body topological quantum effects, such as the fractional quantum hall effect. We build on previous experiments, extending the range of observables to single-site ones using high-resolution objectives and a novel scheme to induce the complex tunneling elements necessary to create topological effects in optical lattices. This novel scheme relies on an anti-magic lattice in which two different hyperfine states of Caesium are trapped in the nodes and anti-nodes of the standing wave potential. Due to a wide Feshbach resonance at low magnetic fields available in Caesium, we will be able to tune the onsite interaction over a broad range. This poster also will give a status report on the progress of the experiment build up so far.

Q 13.6 Mon 16:30 Empore Lichthof

Universal Dynamics in Bose Gases Far from Equilibrium — •Paul Grosse-Bley, Philipp Heinen, Christian-Marcel Schmied, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Far from equilibrium, comparatively little is known about the possibilities nature reserves for the structure and states of quantum many-body systems. Starting from a far-from equilibrium initial configuration a quantum many-body system can approach a non-thermal fixed point exhibiting universal scaling in time and space. Such fixed points have been discussed analytically as well as numerically and have recently been observed in experiments.

Different underlying physical configurations and processes can lead to the universal scaling characterizing the evolution at the fixed point. In particular, the dynamics can either be driven by the reconfiguration and annihilation of (topological) defects populating the system or by conserved redistribution of quasiparticle excitations. We introduce far from equilibrium initial configurations that feature different physical configurations by means of parameter quenches.

In our work we numerically analyze Bose gases in up to three spatial dimensions using the semi-classical truncated Wigner method. We calculate correlation functions in order to extract universal properties of the system. To unravel the underlying physics characterizing the evolution of systems at the non-thermal fixed point we specifically investigate phase correlations and higher order field correlations.

Q 13.7 Mon 16:30 Empore Lichthof

A two-dimensional box trap for bosons with tuneable interactions — •Julian Schmitt, Panagiotis Christodoulou, Maciej Galka, Nishant Dogra, Jay Man, and Zoran Hadzibabic — Cavendish Laboratory, University of Cambridge, UK

Ultracold atoms constitute a powerful platform to study strongly-correlated many-body physics due to the high level of control of their confinement, interactions and dimensionality. While interacting three-dimensional Bose gases exhibit superfluidity induced by Bose-Einstein condensation, two-dimensional Bose gases may become superfluid via the Berezinski-Kosterlitz-Thouless (BKT) mechanism, as observed in e.g. harmonically trapped gases. Probing the nature of the phase transition and the role of interactions, however, has been hampered by the inhomogeneous density distributions of these samples. In this poster, I will present our experimental implementation of a uniform two-dimensional superfluid Bose gas in an optical box trap, which provides access to the thermodynamics and genuine out-of-equilibrium dynamics over the entire system size. The two-dimensional confinement of the gas is realised by repulsive light sheets that allow to dynamically change the trap frequency using a digital micromirror device (DMD). Similarly, the in-plane variable box potential is derived from another DMD acting as an amplitude mask. Finally, our ^{39}K sample allows us to also vary the atomic interactions by employing a magnetic Feshbach resonance. Using the highly tuneable platform, we determine the thermodynamic equation of state of the gas and investigate the elementary excitations by driving the system out of equilibrium.

Q 13.8 Mon 16:30 Empore Lichthof

Dynamical variational approach to Bose polarons at finite temperatures — •David Dzsotjan[1], Richard Schmidt[2], and Michael Fleischhauer[1] — [1]TU Kaiserslautern, Kaiserslautern, Germany — [2]Max-Planck-Institute of Quantum Optics, Garching, Germany

Polarons appear as the result of interaction between a large number of majority particles and a few impurities. Here, we discuss the interaction of a mobile quantum impurity with a Bose-Einstein condensate of atoms at finite temperature. To describe the resulting Bose polaron formation we apply a dynamical variational approach to an initial thermal gas of Bogoliubov phonons. We study the polaron formation after switching on the interaction, e.g., by a radio-frequency (RF) pulse from a non-interacting to an interacting state (injection spectrum). We calculate the real-time impurity Green's function and discuss its temperature dependence. Furthermore, we determine the RF absorption spectrum and find good agreement with recent experimental observations. We predict temperature-induced shifts and a substantial broadening of spectral lines. The analysis of the real-time Green's function reveals a crossover to a linear temperature dependence of the thermal decay rate of Bose polarons as the unitary interaction regime is approached. We also show the results of our work concerning the polaronic ejection spectrum, i.e., when from a steady-state polaron one transfers the impurity to a state where it no longer interacts with the majority bosons.

Q 13.9 Mon 16:30 Empore Lichthof

Quantum State Tomography of Ultracold Atoms in Optical Superlattices via Machine Learning — •Guo-Xian Su[1,2], Zhen-Sheng Yuan[1,2], and Jian-Wei Pan[1,2] — [1]Physikalisches Institut, Ruprecht-Karls-Universitat Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

Optical superlattices enabled preparation of quantum many-body states with ultracold atoms, however, traditional methods of detection and reconstruction of these states requires exponential amount of computational resources. Following recent development of machine learning technics, we demonstrate the use of restricted Boltzmann machine to reconstruct complex quantum states up to 10 Qu-bits prepared with $\sqrt{SWAP}$ operation in superlattices with less than 1000 measurements, which is impossible with brutal-force tomography. This method can be useful for large-scale quantum simulation with ultracold atoms.

Q 13.10 Mon 16:30 Empore Lichthof

Probing entanglement in many-body systems — •Julian Léonard, Robert Schittko, Sooshin Kim, Joyce Kwan, and Markus Greiner — Harvard University, Cambridge, MA, USA

Entanglement is one of the most intriguing features of quantum mechanics. It describes non-local correlations between quantum objects, and it is at the heart of quantum information sciences. In a many-body system, the entanglement can reveal key properties of the underlying physics, which are elusive to other observables.

Here, we elucidate the entanglement properties in different pure quantum states far from equilibrium by measuring a number of entanglement quantities. Firstly, we study the dynamics in a Luttinger liquid after a quantum quench. We observe the formation of bipartite entanglement through the spreading of quasi-particles, which give access to the system's Luttinger parameter. Secondly, we prepare a strongly disordered Bose-Hubbard system far from equilibrium. We identify the emergence of many-body localization by the logarithmically slow formation of entanglement in the system. Finally, we study the weakly disordered Bose-Hubbard system, and identify a spatially separated, sparse-resonant structure, which persists into non-factorizable higher-order correlations.

Q 13.11 Mon 16:30 Empore Lichthof

Critical properties of the extended Bose-Hubbard model with global interactions — Shraddha Sharma[1], •Rebecca Kraus[2], Simon B. Jager[2], Tommaso Roscilde[3,4], and Giovanna Morigi[2] — [1]The Abdus Salam International Center for Theoretical Physics, Strada Costiera 11, 34151 Trieste, Italy — [2]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [3]Laboratoire de Physique, CNRS UMR 5672, Ecole Normale Supérieure de Lyon, Université de Lyon, Ens de Lyon, Université Claude Bernard, CNRS, Laboratoire de Physique, F-69342 Lyon, France — [4]Institut Universitaire de France, 103 boulevard Saint-Michel, F-75005 Paris, France

We consider a bosonic gas in a two-dimensional optical lattice. The atoms interact via s-wave scattering and via the global interactions induced by the coupling with a cavity. The phase diagram here is characterized by a Mott-insulator (MI), superfluid (SF), charge-density (CDW) wave, and supersolid (SS) phase, which emerge from the interplay between kinetic energy, contact interaction, and global interactions. We determine the entanglement entropy and entanglement spectrum across the phase diagram by means of a controlled perturbative expansion above the mean-field ground state. We relate their behavior to the physical excitation spectrum and discuss the nature of the phase transitions.

Q 13.12 Mon 16:30 Empore Lichthof

Light-matter interactions in cold dysprosium atoms — •Marcel Trümper[1], Niels Petersen[1,2], and Patrick Windpassinger[1,2] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany

The fundamental understanding of light-matter interactions and associated phenomena is one of the central endeavors in quantum optics. Extensive research has been performed on a plethora of different systems, including cold and ultra-cold atomic ensembles covering nearly all elements from the periodic table. We are interested in the experimental study of light-matter interactions in dense dipolar media from atoms with large magnetic moments. Dysprosium is the perfect choice for these experiments, since it is the most magnetic element with a magnetic dipole moment of 10 Bohr-magneton.

With this poster we report on recent activities and future work in our laboratory. First, we present results from spectroscopic studies of the 1001 nm ground state transition in dysprosium [arXiv:1907.05754], where we determined the lifetime and polarization of the excited state and measured the isotope shifts of three bosonic isotopes. Further, we give a perspective on our work towards studies of light-propagation effects in dense samples from cold dysprosium atoms. To this end, we report on a microscopic optical dipole trap, which will enable us to achieve the desired densities for our experiments.

Q 13.13 Mon 16:30 Empore Lichthof

Quantifying Entanglement in Bose-Einstein-Condensates using Entropic Uncertainty Relations — •Bjarne Bergh and Martin Gärttner — Kirchhoff-Institut für Physik, Universität Heidelberg, Germany

Entanglement is a key property of quantum mechanical systems and an elementary building block in many quantum mechanical applications. Bose-Einstein-Condensates form interesting systems to study nonlocal entanglement as they allow for precise control of quantum mechanical correlations between many thousand particles and on macroscopic length scales.

Entanglement between two spatially separated subsystems of a Bose-Einstein-Condensate has recently been demonstrated via EPR-Steering. However, this does not allow for a quantitative estimate of the entanglement present in the system. The main difficulty here arises from being very limited in the set of experimentally available observables.

We demonstrate how entropic uncertainty relations, applied to the correlations between two subsystems when measured in multiple sets of bases, can be used to gain bounds on the entanglement entropy. Besides being another entanglement witness, this also provides a bound on the quality of the entangled state.

Q 13.14 Mon 16:30 Empore Lichthof

Partial Distinguishability and Coherence in Many-Body Systems — •Eric Brunner, Christoph Dittel, Gabriel Dufour, and Andreas Buchleitner — Quantenoptik und -statistik, Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Many-body interference in the dynamics of identical particles is controlled by their mutual indistinguishability. This can be tuned by addressing suitable “label” degrees of freedom. Through a systematic analysis of coherence in the dynamical modes, limited by entanglement between dynamical and label degrees of freedom, we define a hierarchy of indistinguishability measures. Identifying robust signatures of many-body interference in randomized correlation measurements allows us to uncover the coherence structure of a given input state, and, therefore, to assess the degree of indistinguishability. This paves the way for an experimental quantification of partial distinguishability in general non-interacting many-body systems.

Q 13.15 Mon 16:30 Empore Lichthof

Detecting Bell correlations in a Bose-Einstein condensate — •Adrian Braemer and Martin Gärttner — Kirchhoff-Institut für Physik, Heidelberg

Bell correlations are the strongest type of quantum correlations and serve as a resource in many quantum information processes. They are detected through violations of Bell's inequalities, such as the CHSH inequality. This has been shown in many experiments typically using discrete-valued observables. For continuous variable systems violation has been achieved using squeezed states of light. However, highly entangled states have also been demonstrated with ultracold atoms. Motivated by this we propose a scheme to detect Bell correlations in a spinor BEC allowing a Bell test on a mesoscopic ensemble of massive particles.

Q 13.16 Mon 16:30 Empore Lichthof

Dynamics of entanglement creation between two spins coupled to a chain — •Christian Otto[1], Pierre Wendenbaum[1,2], Bruno G. Taketani[3], Endre Kajari[1], Giovanna Morigi[1], and Dragi Karevski[2] — [1]Universität des Saarlandes — [2]Universite de Lorraine — [3]Universidade Federal de Santa Catarina

We study the dynamics of entanglement between two spins which is created by the coupling to a common thermal reservoir. The reservoir is a spin-1/2 Ising transverse field chain thermally excited, the two defect spins couple to two spins of the chain which can be at a macroscopic distance. In the weak-coupling and low-temperature limit the spin chain is mapped onto a bath of linearly interacting oscillators using the Holstein-Primakoff transformation. We analyse the time evolution of the density matrix of the two defect spins for transient times and deduce the entanglement which is generated by the common reservoir. We discuss several scenarios for different initial states of the two spins and for varying distances.

Q 13.17 Mon 16:30 Empore Lichthof

Optical Dipole Trap as a Source of Ultracold Atoms in Microgravity — •Marian Woltmann[1], Christian Vogt[1], Sven Herrmann[1], Claus Lämmerzahl[1], and The PRIMUS-Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM) — [2]LU Hannover, Institute of Quantum Optics

Cold atoms have proven to be effective tools with wide applications in measuring weakest forces and thereby in testing fundamental physics e.g. the weak equivalence principle. The sensitivity of such atom interferometer measurements scales with the square of the interrogation time, typically limited by the size of the vacuum chamber. Therefor the step to employ atom interferometers in weightlessness offers the potential of highly increased sensitivities. 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. As the dipole trap is based on optical interactions only, Feshbach resonances will become feasible in microgravity. Furthermore the optical dipole trap allows to trap all magnetic sub-states and offers an enhanced symmetry of the trapping potential. This poster will give an overview of the experiment and report on latest results. The PRIMUS-project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1642.

Q 13.18 Mon 16:30 Empore Lichthof

A high-flux source of rubidium Bose-Einstein condensates for atom interferometry — •Dorothee Tell, Christian Meiners, Henning Albers, Dennis Schlippert, and Ernst M. Rasel — Leibniz Universität Hannover, Institut für Quantenoptik, Germany

Using Bose-Einstein condensates (BEC) for atom interferometry enables increased sensitivity for inertial measurements. A large number of atoms in the interferometer lowers the shot-noise of the readout, while a high repetition rate - usually limited by the duration of BEC creation - is needed for fast averaging and increased temporal resolution. Therefore we aim for a fast source producing a high number of atoms in a quantum-degenerate state.

We present the implementation of a rubidium source which uses a sequence of a dual MOT system loading $5 \cdot 10^9$ atoms in 200 ms and a high power crossed optical dipole trap to create BECs. Dynamically shaped potentials are used to optimize the speed and efficiency of evaporative cooling towards unprecedented BEC flux. Finally, we evaluate the impact of this source on experiments in a 10 m baseline in the

Hannover Very Long Baseline Atom Interferometry facility (VLBAI).

This work is funded by the DFG as a major research equipment (VLBAI facility), via the CRCs 1128 “geo-Q” and 1227 “DQ-mat”, under Germany’s Excellence Strategy (EXC 2123) “QuantumFrontiers”, and by the Federal Ministry of Education and Research (BMBF) through the funding program Photonics Research Germany (contract number 13N14875).

Q 13.19 Mon 16:30 Empore Lichthof

Performance of a CMOS based atom chip — Felix Wenzl[1], David Werban[1], Philipp Neumann[1], Alexander Nemecek[1], Thomas Fernholz[2], Mark Fromhold[2], and •Christian Koller[1] — [1]Fachhochschule Wiener Neustadt, Johannes Gutenbergstraße 3, 2700 Wiener Neustadt, Austria — [2]School of Physics and Astronomy, The University of Nottingham, University Park Nottingham, NG7 2RD, UK

Neutral atoms and atom chip technology have proven to be an excellent toolkit for the realisation of experiments in fundamental science such as atom interferometry or the study of one-dimensional systems. Ongoing efforts are currently developing them into versatile platforms for quantum-based sensors for e.g. gravity or magnetic fields. As atom chips are based on the tools of modern semiconductor fabrication, they provide a pathway to the very large-scale integration of quantum devices. Nevertheless, current state-of the-art atom chips are usually fabricated as prototypes in research facilities, not using the vast capabilities of modern, commercial semiconductor foundries, resulting in high costs and low throughput of these devices. In this work we will present test results for a next generation atom chip fully build in a commercial foundry utilizing 0.35 μm Complementary Metal Oxide Semiconductor (CMOS) technology. We will show that this chip can reach specification comparable to state-of-the art atom chips but extends the standard capabilities due to the integration of multilayer structures, on-board current switching capabilities, reconfigurable magnetic traps, integrated photodetection and read-out electronics.

Q 13.20 Mon 16:30 Empore Lichthof

Controlling multipole moments of a magnetic chip trap — •Tobias Liebmann and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

Magnetic chip traps are a standard tool for trapping atoms [1,2]. These are robust devices with multiple fields of use ranging from fundamental physics experiments [3] to applications of inertial sensing [2]. While magnetic traps do provide good confinement potentials, they are not necessarily harmonic, in particular they can exhibit strong cubic anharmonicity. In this contribution, we will discuss methods of designing printable 2D wire guides, which compensate unfavorable multipole moments. A theoretical approach is proposed to reduce the unwanted multipole moments of a Z-chip trap by introducing a small disturbance to the standard wire configuration. Using a suitable representation of the disturbance, the resulting magnetic field is calculated via the Biot-Savart law. This allows one to calculate the multipole moments in proximity to the trap minimum, as a result the rogue multipole moments can be minimized.

[1] J. Reichel, and V. Vuletic, eds. *Atom chips.* John Wiley & Sons, 2011.
[2] M. Keil, et al. "Fifteen years of cold matter on the atom chip: promise, realizations, and prospects." *Journal of Modern Optics* 63, 1840 (2016).
[3] D. Becker, et al. "Space-borne Bose-Einstein condensation for precision interferometry." *Nature* 562, 391 (2018).

Q 13.21 Mon 16:30 Empore Lichthof

Improved Laser System for Optical Trapping of Neutral Mercury — •Rudolf Homm, Daniel Preissler, 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. The five stable bosonic isotopes can be used to form ultra cold Hg-dimers through photo-association in connection with vibrational cooling by applying a specific excitation scheme.

The laser system consists of an ECDL at 1014.8 nm followed by a Yb-fiber amplifier and two consecutive frequency-doubling stages. Due to a 50W-pumplaser at 976 nm the power of the ECDL was amplified to about 12 W. This results in about 5 W at 507.4 nm after the first frequency-doubling cavity.

The limiting factor in generating high power at 253.7 nm so far, was the degradation of the non-linear BBO-crystal used in the second frequency-doubling stage. To avoid this problem, we developed a cavity with elliptical focusing [1], which was already successfully tested in other laser systems [2]. Our goal is to replace the actual cavity with one with elliptical focusing to reach higher power at 253.7 nm without degradation. We will report on the status of the experiments.

[1] Preißler, D., *et al.*, *Applied Physics B* **125** (2019): 220
[2] Kiefer, D., *et al.*, *Laser Physics Letters* **16** (2019): 075403

Q 13.22 Mon 16:30 Empore Lichthof

Elementary laser-less quantum logic operations with antiprotons in Penning traps — •Diana Nitzschke[1], Marius Schulte[1], Malte Niemann[2], Juan Cornejo[2], Ralf Lehnert[3], Christian Ospelkaus[2], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute),Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany — [2]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Indiana University

Static magnetic feld gradients superimposed on the electromagnetic trapping potential of a Penning trap can be used to implement laserless spin-motion couplings that allow the realization of elementary quantum logic operations in this system. An important scenario of practical interest is the application to g-factor measurements with single (anti-)protons to test CPT invariance. We discuss the classical and quantum behavior of a charged particle in a Penning trap with a superim- posed magnetic feld gradient. Using analytic and numeric calculations, we find that it is possible to carry out a SWAP gate between the spin and the motional qubit of a single (anti-)proton with high fidelity, provided the particle has been initialized in the motional ground state. We discuss the implications of our findings for the realization of quantum logic spectroscopy in this system.

Q 13.23 Mon 16:30 Empore Lichthof

Semiclassical Laser Cooling in a Strongly Focussed Laser Field — •Maximilian Schumacher, Thorsten Haase, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4a, D-64289 Darmstadt

The semiclassical theory of laser cooling above the Doppler limit describes many experiments in quantum optics and quantum information science. In this contribution this semiclassical laser theory is applied to describe a scenario in which a (classical) laser field is strongly focused. Our investigation is motivated by the 4PiPac experiment [1] performed in Erlangen in which a single ion is trapped in the focus of a parabolic mirror and is driven almost resonantly by a laser field entering this cavity as a plane wave. Modelling this ion by a degenerate multi-level system the influence of the strongly focused laser beam and its peculiar polarization properties on the center-of-mass motion of the ion are explored. Comparison of these results with the corresponding results of a two-level model for the ion exhibit the characteristic effects caused by this peculiar polarization dependence of the laser field.

[1] Alber L., Fischer M., Bader M., Mantel K., Sondermann M., Leuchs G., J. Europ. Opt. Soc. Rap. Public. 13, 14 (2017)

Q 13.24 Mon 16:30 Empore Lichthof

Highly dynamical microwave source with low phase noise for cold atom experiments — •Bernd Meyer, Alexander Idel, Fabian Anders, and Carsten Klempt — Institut für Quantenoptik, Leibniz Universität Hannover

Entangled states in Bose-Einstein condensates (BECs) can be employed for precision metrology and for exploring fundamental physics. The generation of entanglement can be achieved by spin-changing collisions in a spinor Bose-Einstein condensate. This process allows for the creation of pair correlations and full many-particle entanglement within the atomic ensemble. [1]

The preparation of the initial states and the manipulation of the entangled states require the application of tailored microwave fields. The fidelity of the created states is often limited by microwave phase noise. In an atom interferometer, this noise generally deteriorates the interferometric signal. Reduction of the microwave’s phase noise is thus crucial for high-precision measurements at the shot noise level.

We will present a novel microwave source based on FPGA-controlled Direct Digital Synthesis (DDS). The source offers adjustable frequency, phase and amplitude with update times of only 700 ns. When using

RAM of the DDS, shaped pulses with different parameters can be applied. The resulting phase noise is in the range of -125 dBc/Hz to -130 dBc/Hz for offset frequencies of 20 kHz to 20 MHz.

[1] B. Lücke *et al.*, *Phys. Rev. Lett.*, **112**, 155304 (2014).

Q 13.25 Mon 16:30 Empore Lichthof

A high-flux Yb source for atom interferometry using a core-shell MOT — •Robert J. Rengelink, Etienne Wodey, Dennis Schlippert, and Ernst M. Rasel — Leibniz Universität Hannover, Institut für Quantenoptik, Germany

In high-performance atom interferometry the short term stability is ultimately limited by shot-noise and the repetition rate of the experiment. In order enable new geophysical and fundamental science applications of Very Long Baseline Atom Interferometry (VLBAI) it is therefore necessary to develop high-flux sources.

We present a high-flux ytterbium source that can be subdivided into two parts. The first consists of an oven with a microtube array nozzle, a Zeeman slower based on a Hallbach array of permanent magnets, and a 2D-MOT deflection/collimation stage. This produces a cold flux in excess of 10^9 atoms/s into the MOT chamber.

The second part is a two-colour MOT in a so-called core-shell configuration: A hollow beam tuned to the strong ${}^1S_0 \rightarrow {}^1P_1$ transition at 399 nm is applied to capture as much flux as possible and transfers the atoms to a central MOT at the narrow ${}^1S_0 \rightarrow {}^3P_1$ transition at 556 nm which cools them to low temperatures and traps with a long lifetime. Finally, we compare and contrast the core-shell MOT with a sequential two-colour MOT. The VLBAI facility is a major research equipment funded by the DFG. We acknowledge support from the CRCs 1128 "GeoQ" and 1227 "DQ-mat", the Cluster of Excellence 2123 "QuantumFrontiers", and by BMBF (13N14875)

Q 13.26 Mon 16:30 Empore Lichthof

Influence of silicon dioxide layer on losses and switching behaviour of electro-optical modulators in $LiNbO_3$ — •Silia Babel, Felix vom Bruch, Christof Eigner, and Christine Silberhorn — Universität Paderborn, Warburger Str. 100, 33098 Paderborn

The transmission and encoding of information via glass fibers and electro-optical modulation is a well established technology.

Lately, quantum communication becomes more and more important. In order to be able to use classical modulators for quantum communication, these must be optimized according to novel system specifications. The optical losses caused by using the modulators have to be reduced, since qubits, in which the information is encoded, cannot be classically amplified. Furthermore, feed-forward schemes are essential ingredients for quantum communication, but due to their complexity not yet entirely released. To overcome this obstacle, the interplay and functionality between the different components has to be optimized and here, we concentrate on the switching behaviour of the required electro-optical modulators. The platform of choice is lithium niobate waveguide structures. They offer potentially low losses in combination with significantly faster switching behaviour compared to bulk modulators. This can be achieved by a smaller electrode gap, which allows lower switching voltages resulting in a decrease of the switching time. The optical losses as well as the switching behaviour depend on the design of the electrodes. Therefore, in order to achieve faster and lower-loss electro-optical modulators, the losses caused by the electrodes and the switching are examined as a function of the buffer layer.

Q 13.27 Mon 16:30 Empore Lichthof

Self-Induced Transparency in Room-Temperature Dense Rydberg Gases — •Zhengyang Bai[1,2], Weibin Li[1], and Guoxiang Huang[2] — [1]School of Physics and Astronomy, and Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, UK — [2]State Key Laboratory of Precision Spectroscopy, East China Normal University, Shanghai 200062, China

Aggressively large Doppler effects is of the challenge to create static optical nonlinearities in atomic gases beyond ultracold temperatures. We show the creation of strong dispersive optical nonlinearities of nanosecond laser pulses in high number density atomic gases at room temperature. This is examined in a vapor cell setting where the laser light resonantly excites atoms to Rydberg P states through a single-photon transition. Using fast Rabi flopping and strong Rydberg atom interactions, both in the order of GHz, can overcome the Doppler effect as well as dephasing due to thermal collisions between Rydberg electrons and surrounding atoms. In this strong-driving regime both the light intensity and Rydberg interactions contribute to the generation of the optical nonlinearity. We show the emergence of a modified self-induced transparency (SIT) where the stable light propagation relies on the Rydberg interactions. We identify quantitatively that the SIT occurs at smaller (than 2π) pulse areas for higher Rydberg states. We furthermore demonstrate that a conditional optical phase gate can be implemented by harvesting strong Rydberg atom interactions and SIT.

Q 13.28 Mon 16:30 Empore Lichthof

Simulating storage of quantum dot photons in an atom-cavity system — •Maximilian Ammenwerth, Lukas Ahlheit, Wolfgang Alt, Tobias Macha, Pooja Malik, Deepak Pandey, Hannes Pfeifer, Eduardo Uruñuela, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn Wegelerstr. 8, 53115, Bonn, Germany

Large-scale quantum networks based on the synchronized transfer of single photons require efficient light-matter interfaces which can generate and store photons deterministically. In this regard, the small mode volume of fiber-based Fabry-Pérot cavities offers strong light-matter coupling with high-bandwidth. In our experiment a single rubidium atom is coupled to the cavity. Using a cavity-assisted Raman process we recently demonstrated the storage of short light pulses in such a coupled atom-cavity system [1]. The successful storage of a weak coherent wave packet with a full width at half maximum of 5 ns encourages hybrid experiments with semiconductor quantum dots as a single photon source.

We numerically compute the expected storage efficiency for weak coherent and single photon pulses by means of a numerical simulation that takes into account our system parameters as well as a typical pulse shape of quantum dot photons. The optimal control pulse is found from a numerical optimisation based on simulating the system dynamics via the Lindblad master equation.

[1] T. Macha, et al., arXiv:1903.10922v2 (2019)

Q 13.29 Mon 16:30 Empore Lichthof

Designing high precision electronics for an atom interferometer on the ISS — •Alexandros Papakonstantinou[1], Thijs Wendrich[1], Wolfgang Bartosch[1], Christian Schubert[1], Ernst M. Rasel[1], Wolfgang Ertmer[1], and the BECCAL Team[1,2,3,4,5,6,7] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Mikroelektrische Systeme, Leibniz Universität Hannover — [3]Universität Ulm — [4]Ferdinand Braun Institut — [5]Humboldt Universität Berlin — [6]Johannes Gutenberg Universität Mainz — [7]ZARM Universität Bremen

The Einstein equivalence principle has been tested with in dual species atom interferometers. Compared to ground based experiments, the ISS provides a microgravity environment and can therefore increase the free fall time in ground based experiments. For running such an atom interferometer in a space born platform, high precision and compact electronics are needed. Strict requirements for the operation on the ISS such as operation safety and size demand new developments for several electronic components. Based on our experience from other space missions such as the MAIUS 2/3 sounding rocket missions, the new components will be designed to comply with these specific restrictions. In this poster we show the overall design of the electronics and the progress in our work. This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for economic affairs and energy (BMWi) under the grant numbers 50WP1431 and 50WP1700.

Q 13.30 Mon 16:30 Empore Lichthof

Compact, miniaturized and robust electronics for the operation of a dual species atom interferometer on a sounding rocket — •Wolfgang Bartosch, Thijs Wendrich, Alexandros Papakonstantinou, Matthias Koch, Maike Lachmann, Baptist Piest, Wolfgang Ertmer, Ernst Maria Rasel, and the MAIUS-Team — Institut für Quantenoptik, Leibniz Universität Hannover

Quantum sensors based on atom interferometry have become a valuable tool in numerous fields of scientific research. The sensitivity of atom interferometers depends predominantly on the possible free falling time of the coherently split atomic ensemble. Hence working towards a space born experiment, where the free falling time is only limited by the expansion rate of the atomic ensemble, is a logical step. The MAIUS-2/3 sounding rocket missions will be a step towards such a space born experiment by showing the feasibility of a dual species atom interferometer in space. Based on our experience from the predecessor mission MAIUS-1, we improved our electronics to match the needs of a mission with two species. We downsized the electronic components used for MAIUS-1 to fit hardware for dual species operation in an apparatus of the same size. With this poster we present our current progress. The QUANTUS/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 13.31 Mon 16:30 Empore Lichthof

Waveguide integrated superconducting nanowire single-photon detectors made from NbTiN thin films — •Martin A. Wolff[1,2,3,4], Simon Vogel[1,2,3], Matthias Häussler[1,2,3], Lukas Splitthoff[1,2,3], and Carsten Schuck[1,2,3] — [1]Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]SoN - Center for Soft Nanoscience, Busso-Peus-Str. 10, 48149 Münster, Germany — [4]martin.wolff@wwu.de

Superconducting nanowire single-photon detectors (SNSPDs) are an ideal match for integrated quantum photonic circuits because efficient interfaces between waveguide and detector are straightforwardly achieved. Employing a traveling wave geometry allows for simultaneously realizing high detection efficiency, low noise and accurate timing in high-speed operation [1]. Here we show that these performance characteristics are achievable across several photonic integrated circuit platforms using a universal fabrication process. We fabricate SNSPDs on Si3N4, Ta2O5 and LiNbO3 using a room-temperature magnetron sputtering process for niobium titanium nitride (NbTiN) thin films and state-of-art nanofabrication methods. Our process yields detectors with > 80% efficiency, MHz count rates, < 30 ps jitter and milli-Hz dark count rates at the telecommunication wavelength of 1550 nm. Our work opens up the possibility for retrofitting nanophotonic chips with single-photon detectors across a wide range of dielectric material systems. [1] S. Ferrari et al., Nanophotonics, 7, 1725 (2018)

Q 13.32 Mon 16:30 Empore Lichthof

Towards a setup for HBT measurements using small telescopes — •Sebastian Karl[1], Stefan Richter[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany

The ability to measure temporal intensity correlation functions with high SNR and predictable contrast can be regarded as the first step towards spatial Hanbury Brown Twiss (HBT) intensity interferometry [1]. Recently such measurements have been performed using the light of arc lamps [2] and of real stars using large optical [3, 4] and Cherenkov [5] telescopes. We present a setup and laboratory test results of temporal intensity correlation measurements with sub 100 ps resolution using a Xenon arc lamp. Our measurement results fit our theory and simulations [6] extremely well. In the light of recent HBT revival experiments [3, 4, 5] we discuss a setup to measure temporal intensity correlations utilizing small telescopes of 0.5 m diameter and high timing resolution.

[1] R. Hanbury Brown, R. Q. Twiss, Nature 177, 27 (1956). [2] P. K. Tan et al., Astrophysical JL 789, L10 (2014). [3] W. Guerin et al., MNRAS 472, 4126 (2017). [4] W. Guerin et al., MNRAS 480, 245 (2018) [5] N. Matthews et al., arXiv 1908.03587 (2019) [6] R. Schneider et al., Appl. Opt. 57, 7076 (2018).

Q 13.33 Mon 16:30 Empore Lichthof

Fast Photon Storage in an Atom-Cavity System with Raman Cooling — •Lukas Ahlheit, Wolfgang Alt, Maximilian Ammenwerth, Tobias Macha, Pooja Malik, Deepak Pandey, Hannes Pfeifer, Eduardo Uruñuela, and Dieter Meschede — Institute for Applied Physics, Bonn, Germany

Atoms coupled to a high bandwidth fiber-cavity are a promising platform for storing temporally short photons, a versatile information carrier in quantum networks.

In our system the atoms are trapped in a 3D-lattice at the center of the fiber cavity and pre-cooled with a degenerate raman sideband cooling technique [1]. Then carrier-free Raman cooling is used to prepare them close to the 3D motional ground state using the intra-cavity blue detuned dipole trap and a DBR laser. In order to phase lock the DBR to the dipole trap laser, the linewidth of the DBR laser is reduced by optical feedback through a meter-long external cavity to a few tens of kHz.

Photon storage is accomplished with the D2 line of ^{87}Rb through a cavity-assisted two photon Raman process in Λ-configuration. This promises photon generation and storage in a controlled and deterministic way with improved efficiencies compared to our previous work [2]. The simulation for the expected storage efficiency along with the experimental findings are presented.

[1] E. Uruñuela, et al., arXiv:1909.08894 (2019)
[2] T. Macha, et al., arXiv:1903.10922 (2019)

Q 13.34 Mon 16:30 Empore Lichthof

Directly Laser-Written Lab-on-Tip for Nanoscale Sensing — •José Ferreira Neto[1], Jonas Gutsche[1,2], Ashkan Zand[1], Stefan Dix[1], Stefan Guckenbiehl[1], and Artur Widera[1,2] — [1]Physics Department and State Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Erwin-Schrödinger-Str. Gebäude 46, 67663 Kaiserslautern, Germany

Nitrogen-vacancy (NV) centers in diamond have advanced to a highly promising nano-scale probe. A prominent feature of the NV center is optical initialization and readout of its spin degree of freedom, which can also be controlled via microwave fields. Due to low cytotoxicity, relatively long coherence times at room temperature, and its high sensitivity to external fields, it is widely used to detect DC and AC magnetic fields and to sense temperature distributions in biological samples.

We present the incorporation of nanodiamonds containing NV centers into direct-laser-written (DLW) three-dimensional polymer photonic structures on a fiber tip. In addition, we show our approach to integrate a microwave antenna for NV spin control manufactured with metal DLW to the same fiber tip and complement our studies with simulations performed in COMSOL. This paves the way to a fully integrated "Lab-on-Tip" for biological applications.

Q 13.35 Mon 16:30 Empore Lichthof

Incoherent Diffraction Imaging - Utilizing Intensity Interferometry for Imaging with Hard X-Rays — •Stefan Richter[1,2], Fabian Trost[3], Anton Classsen[1,2], Kartik Ayyer[2], Henry Chapman[3,4,5], Ralf Röhlsberger[5,6], and Joachim von Zanthier[1,2] — [1]Universität Erlangen-Nürnberg, Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, Erlangen — [3]Center for Free-Electron Laser Science, DESY, Hamburg — [4]Universität Hamburg, Hamburg — [5]The Hamburg Centre for Ultrafast Imaging, Hamburg — [6]DESY, Hamburg

Intensity correlations were initially used in astronomy for determining the diameter or the separations of stars [1]. Recently, it was shown that this technique can also be employed in the x-ray domain to reveal the arrangement of atoms in crystals or molecules that scatter incoherent x-ray fluorescence photons [2]. Correlating incoherent fluorescence photons, a larger volume of the Fourier space is accessible and elements specific imaging is possible [2]. Here we present numerical simulations of this technique, including correlating photons in 3D Fourier space, rotation of microcrystals when jetted in a beam and normalization of the correlations. We also discuss the influence of different sources of noise.

[1] R. Hanbury Brown, J. Davis, L. R. Allen, Mon. Not. R. astr. Soc. 167, 121 (1974) [2] A. Classen, K. Ayyer, H. N. Chapman, R. Röhlsberger, J. von Zanthier, Phys. Rev. Lett. 119, 053401 (2017).

Q 13.36 Mon 16:30 Empore Lichthof

Mueller matrix microscopy setup for nanoform metrology — •Jana Grundmann, Tim Käseberg, and Bernd Bodermann — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Mueller matrix ellipsometry is an indirect method for measuring optical parameters of a nanostructure. As an extension, the classical Mueller matrix ellipsometer can be combined with a microscope to a Mueller matrix microscope, which can measure Mueller matrices pixel by pixel. We constructed a microscope of this kind in such a way that measurements can be made both in reflection and transmission. Our device is a so called dual-rotating compensator ellipsometer and has a CCD-camera as a detector. In a first step, the light source will be a white LED in combination with different passband filters for monochromatic measurements. It is planned to extend the set-up later with a monochromator and a 1 kW xenon lamp to enable spectroscopic measurements. This system will be used to investigate the capability of imaging Mueller ellipsometry to provide additional information on the shape of nano-scaled structures which cannot be seen in classical bright field microscope images. This is done in particular by analyzing the off-diagonal Mueller matrix elements.

Q 13.37 Mon 16:30 Empore Lichthof

Mechanically decoupling of Quantum Emitters in Hexagonal Boron Nitride — •Felix A. Breuning[1], Michael Hoese[1], Prithvi Reddy[2], Andreas Dietrich[1], Michael K. Koch[1], Konstantin G. Fehler[1,3], Marcus W. Doherty[2], and Alexander Kubanek[1,3] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Laser Physics Centre, Research School of Physics and Engineering, Australian National University, Canberra, ACT 0200, Australia — [3]Center for Integrated Quantum Science and Technology (IQst), Ulm University, D-89081 Ulm, Germany

Single photon sources are essential for novel hybrid quantum systems and might be used in quantum network architectures, like the quantum repeater. The gain of Quantum Emitters in hexagonal Boron Nitride (hBN) are their promising characteristics such as persisting Fourier limited linewidths from cryogenic [1] up to room temperatures [2]. The suggested reason for this observation is the decoupling from in-plane phonon modes. Here, we present our recent results towards identifying the origin of this mechanical decoupling. They strengthen the assumption that the mechanical decoupling could be caused by out-of-plane emitters. The aim of our measurements is a better understanding of single quantum emitters in hBN, which could allow for implementation of novel hybrid quantum systems and quantum optics experiments at room temperature.

[1] A. Dietrich, et al., Phys. Rev. B 98, 081414 (2018)
[2] A. Dietrich, et al., arXiv:1903.02931.

Q 13.38 Mon 16:30 Empore Lichthof

Inverted plasmonic lens designs for ellipsometric form evaluations — •Tim Käseberg[1], Jana Grundmann[1], Thomas Siefke[1,2], Stefanie Kroker[1,3], and Bernd Bodermann[1] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Friedrich-Schiller-Universität Jena, Institute of Applied Physics, 07743 Jena, Germany — [3]Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, 38106 Braunschweig, Germany

For a better sensitivity of polarization-based form information of nanostructures in Mueller matrix ellipsometry, we investigate the use of plasmonic lenses in ellipsometric setups. The classic plasmonic lens consists of a metallic slab with several nanoslits that function as waveguides for surface plasmon polaritons (SPPs). However, due to the need for narrow and deep slits leading to slab thicknesses of about 1 μm and slit widths around 10 - 100 nm, the fabrication of plasmonic lenses is challenging. We present a new design scheme, called inverted plasmonic lens, where instead of travelling through slits SPPs propagate through dielectric ridges with metallic sidewalls. The new design accommodates electron beam lithography, simplifying the fabrication process. In this contribution, we discuss this new design and compare it to the classic design. We used particle swarm optimization and finite element method to simulate lenses with different parameters to design a set of lenses for the application on varying regimes of wavelength and focal length. Additionally, we discuss the application of the inverted plasmonic lens in Mueller matrix microscopy for an advanced metrology of nanostructures with sub-wavelength sized features.

Q 13.39 Mon 16:30 Empore Lichthof

Investigating Electron-Phonon Coupling of Defect Centers in hBN — •Michael K. Koch[1], Andreas Dietrich[1], Michael Hoese[1], Igor Aharonovich[3], Marcus W. Doherty[2], and Alexander Kubanek[1,4] — [1]Insitute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Laser Physics Centre, Australian National University, ACT 2601, Australia — [3]Faculty of Science, University of Technology Sydney, Ultimo, NSW 2007, Australia — [4]IQst, Ulm University, D-89081 Ulm, Germany

Single photon sources are key components for novel hybrid quantum systems, which will allow the implementation of quantum technologies like quantum repeaters or other quantum network architectures. Quantum emitters in hexagonal Boron Nitride (hBN) revealed promising attributes such as a homogeneous linewidth in agreement with the Fourier-Transform limit up to room temperature (RT) [1,2]. However, the full level structure including detailed characteristics of the phononic sideband lack full understanding. Here, we present our recent results leading to a more complete picture of single quantum emitters in hBN. We focus on the persistence of Fourier limited linewidths up to 300K. To examine the emitter level structure of the defect centers, we mainly use resonant (PLE) and off-resonant (PL) photoluminescence spectroscopy. Understanding the underlying physics for the persistence of Fourier limited lines up to room temperature paves the way for the development of novel hybrid quantum systems.

[1] A. Dietrich et al., Physical Review B 98, 081414(R) (2018)
[2] A. Dietrich et al., arXiv:1903.02931 (2019)

Q 13.40 Mon 16:30 Empore Lichthof

Nanomanipulation capabilities and optical coupling of intrinsically identical SiV$^-$ color centers in nanodiamonds — •Elena Steiger[1], Richard Waltrich[1], Stefan Häussler[1], Konstantin Fehler[1], Lukas Antoniuk[1], Liudmila Kulikova[2], Valery Davydov[2], Viatcheslav Agafonov[3], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Universität Ulm, 89081 Ulm, Germany — [2]L.F. Vereshchagin Institute for High Pressure Physics, Russian Academy of Sciences, Moscow 142190, Russia — [3]GREMAN, UMR CNRS CEA 6157, Université F. Rabelais, 37200 Tours, France

Defects in solids, for instance the NV$^-$ or the SiV$^-$ color center in diamond have proven their usability in many applications that require single quantum systems. Nanodiamonds (NDs) featuring single color centers are one possible platform that enables a scalable use of such systems. Functionalizing the NDs for their use in quantum optics and photonics experiments however remains a challenge. We present NDs hosting single negatively-charged silicon-vacancy (SiV$^-$) centers featuring excellent optical properties, like a large Debye-Waller factor, close to Fourier-Transform limited linewidth and a narrow inhomogeneous distribution. We demonstrate nanomanipulation of the NDs, while conserving the optical properties denoting a first step towards the optical coupling of individual centers.

Q 13.41 Mon 16:30 Empore Lichthof

Hybrid assembly of quantum optical elements — •Andreas W. Schell — Leibniz University Hannover, Germany — PTB, Braunschweig, Germany

Bringing quantum technology from the laboratory to real world applications is a complex, but very rewarding, task. It will enable society to exploit the new opportunities the laws of quantum mechanics offer compared to purely classical physics. However, before the new quantum technology can be deployed, platforms to implement such a technology need to be discovered and developed. Here, we will show our ongoing efforts to implement such a platform using the so called hybrid approach for the assembly of quantum photonic elements. This approach is highly flexible and can be adapted to many different material systems and structures. In particular, we will introduce techniques based on scanning probe microscopy and three-dimensional laser writing. The hybrid quantum photonic elements assembled with these approached include emitter coupled to on-chip resonators and waveguides, different kinds of fiber integrated cavities and incorporate a variety of emitter such as NV centers, quantum dots, and defects in two-dimensional materials, such as hexagonal boron nitride. From these examples it can be seen that photonics elements assembled using hybrid techniques might help to facilitate the transition of quantum photonic networks out of lab to real-world applications.

Q 13.42 Mon 16:30 Empore Lichthof

Novel approaches for scanning probe sensing using color centers in diamond at ambient conditions — •Axel Hochstetter, Richard Nelz, and Elke Neu — Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken

The negatively charged nitrogen vacancy (NV) color center in diamond is a bright, photo-stable dipole emitter [1]. Due to its optically addressable spin states it is used for e.g. electrical and magnetic field sensing applications. In recent years, shallowly implanted NV centers in nanopillars have been introduced as scanning probes for high resolution imaging [2]. We showcase novel approaches for these probes to life-science applications. Specifically, the coupling of NV centers via Förster Resonance Energy Transfer (FRET) [3] unlocks new possibilities for all-optical sensing, as we demonstrate using 2-dimensional materials (e.g. WSe2 and graphene). Furthermore, we outline enhanced sensing schemes, using spin-to-charge conversion for NV centers in ambient conditions. [1] Radtke et al., arXiv:1909.03719(2019). [2] Appel et al., Rev. Sci. Instrum. 87 063703 (2016). [3] Nelz et al., Adv. Quantum Technol. 1900088(2019).

Q 13.43 Mon 16:30 Empore Lichthof

Molecular quantum optics on a chip — •Dominik Rattenbacher[1], Alexey Shkarin[1], Jan Renger[1], Tobias Utikal[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light (MPL), Erlangen, Germany — [2]Friedrich-Alexander University (FAU) Erlangen-Nürnberg, Erlangen, Germany

One-dimensional subwavelength waveguides (nanoguides) are very promising candidates for exploring the rich physics of quantum many body systems, since they allow one to couple several emitters, e.g. organic dye molecules, to a single one-dimensional light mode. However, the efficiency of coupling between an individual emitter and a realistic nanoguide is limited by geometric/material constrains and a rich internal level structure of the emitters. To address this issue, one can employ a high-finesse Fabry-Pérot cavity [1] to enhance the emission of molecules into the mode of interest. Here, we report on seven-times enhancement of the coupling by using microring resonators [2]. We report on our progress to improve our experimental platform by advances in the fabrication and the use of higher refractive index materials such as GaP. Together with the ability to manipulate the resonance frequencies of the molecules by static electric fields, we plan to investigate cooperative effects among several emitters [3].

[1] D. Wang et al., Nat. Phys. **15**, 483 (2019)
[2] D. Rattenbacher et al., New J. Phys. **21**, 062002 (2019)
[3] H. R. Haakh et al., Phys. Rev. A **94**, 053840 (2016).

Q 13.44 Mon 16:30 Empore Lichthof

Hybrid 2D material/dye molecule quantum emitter for negligible scattering-induced losses — •Sofia Pazzagli[1], Christian Liedl[1], Bita Rezania[1], Nikolai Severin[1], Jürgen Rabe[1,2], and Arno Rauschenbeutel[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr 15, 12489 Berlin, Germany — [2]IRIS Adlershof, Humboldt-Universität zu Berlin, Zum Großen Windkanal 6, 12489 Berlin, Germany

In this work we will present preliminary results on the development of a novel hybrid solid-state quantum emitter based on single dye molecules intercalated between two monolayers of transition metal dichalcogenides. The latter would provide almost perfect surface passivation and dye protection against photobleaching agents, as e.g. oxygen. Low spectral diffusion and an accordingly narrow and Fourier-limited emission linewidth at cryogenic temperatures of single molecules are expected and are investigated by optical means with a custom-built fluorescence confocal microscope. Being nanometre thin, this novel quantum emitter would be naturally prone to be efficiently couple to the evanescent field supported by nanophotonic devices, such as tapered optical fibers and on-chip high-Q microresonators. Strong light-matter interaction would be ensured as the emitter can be placed directly onto the surface of the nanostructure while causing only minimal scattering losses, hence representing a promising alternative to the currently available solid-state quantum emitters in sub-micrometric size crystals.

Q 13.45 Mon 16:30 Empore Lichthof

Reliable Nanofabrication for color center-based diamond sensors — •Dipti Rani, Oliver Opaluch, Richard Nelz, Mariusz Radtke, and Elke Neu — Saarland University, Campus E2.6, 66123 Saarbrücken

Individual, luminescent crystal defects in diamond, i.e. color centers, are stable, atomically sized quantum systems. Negative nitrogen vacancy (NV) centers represent isolated electronic spins that we manipulate using microwave radiation, while we read-out their spin state optically [1]. To enable nanoscale sensing, we incorporate NVs into highly functional photonic nanostructures. These tip-like structures enable scanning our NV centers close (< 50 nm) to a sample to record nanoscale resolution images e.g. of magnetic fields. We discuss our recent achievements in optimizing dedicated nanofabrication routines for our sensor devices which are crucial in the context of scalability as well as commercialization [2,3]. Results include a process optimizing adhesion of HSQ resists to diamond as well as the search for alternatives to HSQ. We furthermore address the influence of various plasma treatments on NV centers.

[1] M. Radtke et al., Arxiv 1909.03719 (2019)
[2] M. Radtke et al. Micromachines, 10, 718 (2019)
[3] M. Radtke et al., Opt. Mater. Express 9(12), 4716-4733 (2019)

Q 13.46 Mon 16:30 Empore Lichthof

Analysis of polarisation transfer in diamond from NV centers to ^{13}C assisted by P1 centers — •Marit Steiner, Benedikt Tratzmiller, and Martin Plenio — Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, 89081 Ulm, Germany

A known approach to achieve nuclear hyperpolarisation, which has potential to improve the signal to noise ratio in many NMR applications significantly, is to use dynamic nuclear polarisation (DNP), the transfer of polarisation from electron spins to nuclear spins. NV centres in diamond are well known candidates for DNP on ^{13}C nuclear spins due to established initialisation and manipulation procedures, but the dipole dipole interaction between electron and nuclear spins is of low distance range. To provide more polarisation sources we propose to transfer polarisation from a polarised electron spin to nuclear spins assisted by other paramagnetic defects in diamond, like P1 centres that occur naturally in diamond. Furthermore, we analyse possible negative effects due to high P1 concentrations, since interaction between P1 centres could disturb the polarisation transfer from NV centre to ^{13}C, and modify the used DNP protocol to cancel out harmful effects. We use simulations to analyse the polarisation transfer from optically polarised NV centres to ^{13}C nuclei via P1 centres for few spins and derive a semi classical model to simulate the polarisation transfer and diffusion in a diamond.

Q 13.47 Mon 16:30 Empore Lichthof

High-resolution spectroscopy of single-molecule vibrational states in solid-state matrices — •Johannes Zirkelbach[1], Masoud Mirzaei[1], Tobias Utikal[1], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany

We demonstrate a method to measure the linewidths of the vibrational levels of molecules at a high resolution. To achieve this, we populate the first excited state of single molecules using a narrow-band pump laser and monitor the depletion of the excited state population as the frequency of a second narrow-band 'dump' laser beam is tuned through the Stokes-shifted transitions to the vibrational levels of the electronic ground state. This allows us to resolve the linewidths of ground-state vibrational levels at a resolution of a few MHz limited by the wavemeter used. We apply this technique to dibenzoterrylene molecules embedded in para-dichlorobenzene and anthracene matrices at cryogenic temperatures down to 20 mK. We aim to search for potentially long-lived states, which might be interesting for coherent quantum operations.

Q 13.48 Mon 16:30 Empore Lichthof

Reduction of spectral diffusion by applying a sequence of optical control pulses — •Laura Orphal-Kobin[1], Joseph H. D. Munns[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

A quantum network could be realized by photon-mediated entanglement between stationary quantum bits (qubits). For the generation of coherent photons, enabling efficient entanglement operations, lifetime limited emission linewidths are a fundamental requirement.

However, for the negatively charged NV defect centre in diamond, natural linewidths ($\sim$13 MHz) are challenging to achieve. In addition to homogeneous broadening, in particular the change of the optical transition frequency over time caused by fluctuations of the electrostatic environment leads to inhomogeneous broadening of the zero-phonon emission line (ZPL), which is referred to spectral diffusion.

While work is done on optimizing nanostructure designs and nanofabrication methods, active control schemes could be an interesting alternative to suppress spectral diffusion. Pulsed coherent control schemes are expected to modify the average rate of phase accumulated between the emitter states. By applying a sequence of optical π-pulses the ZPL could be stabilized at a target frequency given by the carrier frequency of the pulses.

Here, we present our work towards experimentally implementing an optical control protocol for reducing spectral diffusion of the ZPL of NV defect centres.

Q 13.49 Mon 16:30 Empore Lichthof

Optical Properties of Single Tin-Vacancy Centers in Diamond Nanopillars — •Joseph Munns[1], Cem Torun[1], Julian Bopp[1,2], Laura Orphal-Kobin[1], Natalia Kemf[2], Mathias Matalla[2], Ralph-Stephan Unger[2], Ina Ostermay[2], Alexander Külberg[2], Andreas Thies[2], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand Braun Institut, Berlin, Germany

The tin-vacancy centre in diamond (SnV) has very recently attracted increasing interest as a promising system for quantum information protocols, as a candidate which may offer both the optical as well as the spin coherence properties needed for a robust spin-photon interface in a quantum node. Motivated by this, we present our progress towards investigating the feasibility of deploying the SnV for the generation of resource states for quantum communication protocols. First and foremost, this necessitates the ability to reliably generate and control single SnVs with the required properties. In this work, we therefore focus upon the characterisation of optical and spin coherence properties of SnVs, which are artificially generated with differing implantation strategies and integrated into diamond nanopillars. This enables a route to optimise the yield of nanopillar integrated single SnVs, and therefore provides a means to realise a scalable spin-photon quantum node.

Q 13.50 Mon 16:30 Empore Lichthof

Entanglement of High-Energy Photons — •Michael E. N. Tschaffon[1], Maxim A. Efremov[1,2], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt (DLR), D-89077 Ulm, Germany

For decades, photons have been used extensively as a tool to verify in a laboratory many practical effects based on entanglement. Nowadays, pairs of such entangled photons are mostly produced for visible light by means of parametric down-conversion. However, many applications require sources operating in other domains such as the radio frequency or even the X-ray domain. We consider the decay of positronium (a bound state comprised of an electron and a positron) in its ground state as a new source of two high-energy entangled photons. The ground state is treated non-relativistically whereas the decay is examined perturbatively in the framework of QED. We investigate the degree of entanglement of the produced photons in both polarization and momentum.

Q 13.51 Mon 16:30 Empore Lichthof

Time emergence in the coherent state basis — •Sebastian Gemsheim and Jan-Michael Rost — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Deutschland

Is time fundamental or emergent? This is an old question but to date the answer remains elusive. Advocating for the latter, we examine a possible mechanism for its emergence. The time-dependent Schroedinger equation can be obtained from the time-independent Schroedinger equation for a bipartite system [1], comprised of a quantum 'clock' and a generic quantum system. Consequently, the time parameter emerges from an underlying entanglement between both subsystems.

Specifically, we take a single harmonic oscillator as the 'clock' in the coherent state basis. This allows us to explore the significance of having two degrees of freedom in the complex plane which manifests itself as a complex time parameter. We derive a one-dimensional parametrized curve in the classical limit of large 'clock' energies, i.e., a one-dimensional real-time parametrization. To be operational as a clock, the 'clock' energy must be large in order to effectively distinguish between different 'clock positions' and we quantify the achievable, energy-dependent resolution. In addition, we investigate analogies and similarities to the imaginary-time formalism, e.g., imaginary-time propagation.

[1] J. S. Briggs, S. Boonchui, and S. Khemmani, Journal of Physics A: Mathematical and Theoretical 40, 1289 (2007)

Q 13.52 Mon 16:30 Empore Lichthof

Bayesian inference of CSL-Parameters — •Björn Schrinski and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen, Duisburg

Collapse models [1] are a possible explanation for the absence of quantum mechanical superpositions on macroscopic scales. The most prevalent model is the Continuous Spontaneous Localization (CSL) model [2] being under intensified scrutiny in recent years [3]. While uninformative Bayesian parameter estimation can be applied to assess the degree to which a specific experiment verifies quantum mechanics on macroscopic scales [4], we show here how one can use the Bayesian approach to combine all experimental observations to obtain conservative exclusion regions in the CSL parameter space.

[1] Bassi et al., Rev. Mod. Phys. 85, 471 (2013)
[2] G.C. Ghirardi et al., Phys. Rev. A 42, 78 (1990)
[3] M. Carlesso et al., Springer Proceedings in Physics 237, 1 (2019)
[4] Schrinski et al., Phys. Rev. A 100, 032111(2019)

Q 13.53 Mon 16:30 Empore Lichthof

Phonon pair creation by tearing apart quantum vacuum fluctuations — •Florian Hasse[1], Deviprasath Palani[1], Frederick Hakelberg[1], Philip Kiefer[1], Matthias Wittemer[1], Ulrich Warring[1], Tobias Schaetz[1], Christian Fey[2], and Ralf Schützhold[3] — [1]Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Strasse 3, 79104 Freiburg — [2]Universität Hamburg, Fachbereich Physik, Luruper Chaussee 149, 22761 Hamburg — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden

We switch the trapping field of two ions sufficiently fast to tear apart quantum vacuum fluctuations and, thereby, create squeezed states of motion [1]. This process can be interpreted as an experimental analog to the particle pair creation during a cosmic inflation in the early universe [2] and is accompanied by the formation of entanglement in the ions' motional degree of freedom [3]. Hence, our platform allows studying the causal connections of squeezing, pair creation, and entanglement and might permit to cross-fertilise between concepts in cosmology and applications of quantum information processing.

[1] Wittemer, M. et al. Phys. Rev. Lett. 123, 180502 (2019).
[2] Schuetzhold, R. et al., Phys. Rev. Lett. 99, 201301 (2007)
[3] Fey, C. et al., Phys. Rev. A 98, 033407 (2018)

Q 13.54 Mon 16:30 Empore Lichthof

Topological Protection in non-Hermitian Haldane Honeycomb Lattices — Pablo Reséndiz-Vázquez[1], •Konrad Tschernig[2,3], Armando Perez-Leija[2,3], Kurt Busch[2,3], and Roberto de J. León-Montiel[1] — [1]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Apartado Postal 70-543, 04510 Cd. Mx., México — [2]Max-Born-Institut, Max-Born-Straße 2A, 12489 Berlin, Germany — [3]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, D-12489 Berlin, Germany

Topological phenomena in non-Hermitian systems has recently become a subject of great interest in the photonics and condensed-matter communities. In particular, the possibility of observing topologically-protected edge states in non-Hermitian lattices has sparked an intensive search for systems where this kind of states is sustained. Here, we present the first study on the emergence of topological edge states in a two-dimensional Haldane lattice endowed with balanced gain and loss. We show that edge states can be observed in the trivial $\mathcal{PT}$-symmetric phase, that is, when the gain and loss are absent, as well as in the broken $\mathcal{PT}$-symmetric phase, that is, when the spectrum of the system's Hamiltonian is not entirely real. Remarkably, we find that this behavior is universal in the sense that any geometry of the lattice edge, namely zigzag, bearded or armchair supports edge states. These results demonstrate that two-dimensional topologically-protected edge states may exist even in the absence of $\mathcal{PT}$ symmetry.

Q 13.55 Mon 16:30 Empore Lichthof

Purcell-Enhanced Emission from Individual SiV- Center coupled to Photonic Crystal Cavity — •Niklas Lettner[1], Konstantin Fehler[1,2], Anna Ovvyan[3], Lukas Antoniuk[1], Nico Gruhler[4], Valery Davydov[5], Viatcheslav Agafonov[6], 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, Albert-Einstein-Allee 11, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Karlsruhe Institute of Technology (KIT), Institute of Nanotechnology, Germany — [5]L.F. Vereshchagin Institute for High Pressure Physics, Russian Academy of Sciences, Troitsk, Russia — [6]GREMAN, UMR CNRS CEA 6157, Universit F. Rabelais, France

The combination of classical integrated photonic structures with color centers in diamond, like the Nitrogen Vacancy (NV^-) or the Silicon Vacancy (SiV^-) Center, offer a promising platform for on-chip quantum optics experiments. We combine silicon nitride photonic crystal cavities with color centers in nanodiamonds in a hybrid approach. We show the experimental results coupling NV centers efficently to a photonic crystal cavity mode [1] and the purcell enhanced emission of individual SiV^- centers in nanodiamonds with a Purcell factor of 4 [2]. In this poster we lay out the details of our experiments.

[1] Fehler, Konstantin G., et al. ACS Nano 2019, 13, 6, 6891-6898.
[2] Fehler, Konstantin G., et al. preprint arXiv:1910.06119 (2019).

Q 13.56 Mon 16:30 Empore Lichthof

The interaction of a three-level system with quantized light — •Hendrik Rose[1], Daria V. Popolitova[2], Olga V. Tikhonova[2], Polina R. Sharapova[1], and Torsten Meier[1] — [1]Department of Physics, University of Paderborn, Warburger Straße 100, D-33098 Paderborn, Germany — [2]Faculty of Physics, Moscow State University, Leninskie Gory, 1, Moscow, 119991 Russia

Light-matter interaction described with a fully quantized model provides the possibility of utilizing quantum correlations of light [1]. Especially the excitation of materials by nonclassical light can lead to new effects and applications [2] that can be of special interest for quantum metrology and quantum communication.

Our investigations were performed using a Jaynes-Cummings-like model with three electronic levels and two light states, where coherent and squeezed states were considered. Our system contains different loss mechanisms, namely, dephasing, cavity and radiative losses.

The energy level population dynamic was calculated, this dynamic is a unique signature, determined by the photon statistics. Electromagnetically induced transparency (EIT) is demonstrated with quantized light. Special features of the EIT regime were found in the case of excitation by squeezed light. Moreover, quantum correlations between fields were studied.

[1] P.R. Sharapova & O.V. Tikhonova, Quantum Electronics **42**, 199 (2012).

[2] K.V. Zapyantsev & O.V. Tikhonova, Bull. Russ. Acad. Sci. Phys. **82**, 1394 (2018).

Q 13.57 Mon 16:30 Empore Lichthof

Generating two-mode squeezing through measurement-induced nonlinearity — •Matvei Riabinin, Polina Sharapova, Tim J. Bartley, and Torsten Meier — University of Paderborn, Warburger Strasse 100, D-33098 Paderborn, Germany

In optics, nonlinear effects such as parametric down-conversion (PDC) can generate entangled states, quadrature squeezing, and other nonclassical effects. The generation of PDC typically requires strong light intensities since the efficiency of this effect is low. Another way of creating such nonlinear transformations in quantum optics is to use so-called measurement-induced nonlinearities, where nonlinear effects are acquired by applying detection. The advantage of using detection compared to PDC is that fewer incident photons are required to generate nonclassical effects, which makes detection useful at low photon number regime. Acquired effects, however, have a probabilistic nature. In our work, we model a two-mode interferometer where we input different states such as a coherent state and single-photon state and apply detection. We analyze the acquired nonclassical property such as two-mode squeezing at the output. We present an analytical solution for the quantum state at the output and show that detection leads to two-mode squeezing which is absent without detection. In the considered interferometer, it is also possible to generate quantum states similar to two-mode coherent state superposition with high fidelity. Also, we model potential losses inside the interferometer to analyze the possibility of the experimental implementation.

Q 13.58 Mon 16:30 Empore Lichthof

The discrete and continuous fractional Fourier transform applied to entangled two-photon states — •Malin Kück[1,2], Kurt Busch[1,2], and Armando Perez-Leija[1,2] — [1]Humboldt-Universität zu Berlin — [2]Max-Born-Institut, Berlin

Spontaneous parametric down-conversion (SPDC) is a nonlinear optical process that takes place in birefringent crystals where high-energy pump photons are converted into pairs of low-energy signal and idler photons. Depending on the crystal shape and the pump field the emerging photon pairs may exhibit a certain degree of correlation. In this contribution we use the fractional Fourier transform to externally tailor the correlations of photon pairs generated in SPDC sources. We show that arbitrary degrees of intensity correlations can be obtained by applying the Fourier transform of fractional orders to the output states of SPDC sources. In doing so, we compute the dynamics of two-photon light traversing discrete and continuous fractional Fourier transformers, that is, waveguide arrays and GRIN optical media. Moreover, we consider different entanglement criteria to characterize the evolving photon pairs.

Q 13.59 Mon 16:30 Empore Lichthof

Towards generation of Squeezed States of Light at the Rb D1 line — •Torben Sobottke[1,2] and Roman Schnabel[1,2] — [1]Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

The unique non-classical properties of squeezed states of light can be widely used, for example in quantum limited metrology, quantum communication, spectroscopy or microscopy. Within the cluster of excellence "Advanced Imaging of Matter", we started a project which aims at building a portable, tunable, continuous wave squeezed light source operating around the Rb D1 line, thus in the wavelength range from 795nm to 805nm. This device will be used to study the interaction of squeezed light with atoms, ultracold atom gases or BECs. In the poster, we will present the current design ideas, and will especially focus on the challenges to counteract radiation damage of the SHG and OPO due to the near-UV pump light.

Q 13.60 Mon 16:30 Empore Lichthof

A robust, compact ion-trap quantum computer — •Verena Podlesnic[1], Ivan Pogorelov[1], Thomas Feldker[1], Thomas Monz[1], Philipp Schindler[1], and Rainer Blatt[1,2] — [1]University of Innsbruck, Department of Experimental Physics, Technikerstraße 25/4, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaft, Technikerstraße 21a, 6020 Innsbruck, Austria

Quantum computers promise to solve specific problems exponentially faster than today's classical computers. Especially trapped ions have been proven to be promising candidates for the realization of quantum computers as emphasized by the demonstration of high high-fidelity gates on a small number of physical quantum bits [1].

The objective of the project is to realize a robust and compact ion-trap quantum computer with scalable components that can be operated by non-specialist users. In the first iteration we are going to implement a linear Paul trap. In the long term a microfabricated multi-segment ion-trap with the capability of storing 50 $^{40}Ca^+$-qubits will be installed. Full control of these qubits is provided by simultaneous single-ion addressing via fiber arrays. All required components are going to be integrated with the the ion-trap apparatus in compact 19" racks.

Here, we will present the current status of the experimental setup.

[1]J. Benhelm, G. Kirchmair, C. Roos, R. Blatt "Towards fault-tolerant quantum computing with trapped ions", Nature Phys. 4 463 (2008)

Q 13.61 Mon 16:30 Empore Lichthof

Developments towards Microwave-driven high-fidelity Quantum logic gates in multilayer ion traps — •Jonathan Morgner[1,2], Giorgio Zarantonello[1,2], Nicolás Pulido[1,2], Henning Hahn[2,1], Amado Bautista-Salvador[2,1], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Physikalisch-Technische Bundesanstalt, Braunschweig

Scalable quantum computation relies on a universal set of high-fidelity gate operations. Surface-electrode ion traps combined with the microwave near-field approach [1] are a promising candidate for both scalability and high-fidelity operations [2, 3].

In this poster, multiple developments for reducing radial mode errors are presented. A pulse shaped microwave two-qubit gate-scheme for resilience against radial mode instabilities is presented. Two-qubit gates with fidelities above 99.5% using this modulation-scheme were recently reported [4].

Furthermore, a setup - currently under construction - is presented, where Ar^+ bombardment will be used to clean the electrode surface from contaminants, which has been shown to reduce the heating rate of trapped ions [5].

References:
[1] C. Ospelkaus et al., Phys. Rev. Lett. 101 090502 (2008)
[2] T. P. Harty et al., Phys. Rev. Lett. 117, 140501 (2016)
[3] A. Bautista-Salvador et al., New. J. Phys. 21 043011 (2019)
[4] G. Zarantonello et al., arXiv:1911.03954 (2019)
[5] D. A. Hite et al., Phys. Rev. Lett. 109, 103001 (2012)

Q 13.62 Mon 16:30 Empore Lichthof

Coherent control of ions in a surface trap using Raman lasers — •Benjamin Wilhelm[1], Lukas Gerster[1], Pavel Hrmo[1], Martin van Mourik[1], Philipp Schindler[1], Thomas Monz[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21A, 6020 Innsbruck, Austria

Trapped atomic ions offer an advanced platform to realise universal gate operations for performing arbitrary quantum computation. One remaining major challenge is scaling up the number of qubits, such that quantum error correction on logical qubits may be performed. We use a cryogenically cooled planar surface trap with multiple trapping zones as an approach to overcome this challenge. This setup supports the confinement of two ion species, $^{40}Ca^+$ and $^{88}Sr^+$. By using the $^{40}Ca^+$-ion as an optical qubit, we are able to reach estimated coherence times up to 20 ms and create maximally entangled $^{40}Ca^+$-$^{40}Ca^+$ states with fidelities of 98.5(5) %. We plan on using the second species for recooling the motional modes of the ion string. Here we present a Raman beam setup to extend the coherent control of our system to ground state qubits.

Q 13.63 Mon 16:30 Empore Lichthof

EIT based storage and manipulation of light pulses with cold atoms in HCF — Wei Li[1,2], •Parvez Islam[1], Di Hu[1,2], and Patrick Windpassinger[1] — [1]Institut für Physik, Johannes-Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]School of Instrumentation and Opto-electronic Engineering, Beihang University, XueYuan Road 37, 100191 Beijing, P. R. China

Long distance quantum communications require the storage and on demand retrieval of qubits. A reliable light storage platform is using EIT to store light in the atomic coherence (spin waves). Combined with the potential of HCPCFs leads to enhanced light matter interaction and long-distance transport of quantum information. Furthermore, equipped with an optical conveyor belt, which can help transport the atomic ensembles, opens doors for realizing quantum registers by preparing a chain of atomic ensembles with stored photons.

We present our experiment of light storage and retrieval in an optical lattice. To this end we have successfully established storing in an optical lattice with storage times comparable to our transport times. The atomic ensemble is first loaded from a MOT and with the help of our optical conveyor belt transported into the hollow core fiber where we demonstrated successful storage of a light pulse. The storage has been optimized with the help of a circular polarized lattice along with a *magic* magnetic field and optical pumping to clock states. Subsequently, we aim to demonstrate light retrieval after transportation of the atomic ensemble through macroscopic distances.

Q 13.64 Mon 16:30 Empore Lichthof

Towards Cluster State Simulation of the (1+1)-dimensional Lattice Schwinger Model — •Stephan Schuster[1], Marc-Oliver Pleinert[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91052 Erlangen, Germany

In recent years, several quantum simulations of complex physical systems have been performed [1,2]. In these simulations, the well-known quantum circuit model was implemented. This model of quantum computation is based on unitary operations applied onto qubits in a time-ordered sequence. The cluster state model - proposed by Raussendorf and Briegel - on the other hand, is an alternative, but equivalent model for quantum computation [3]. It avoids the complex gate realisations of the circuit model by performing the quantum computation through, potentially adaptive, projective measurements on a group of highly entangled multi-qubit states - the cluster states. Here, we investigate the possibility of the quantum simulation of the (1+1)-dimensional lattice Schwinger model with such cluster states. Besides avoiding complex gate realisations, this might also offer a more efficient way for the simulation, since non-adaptive measurements on the different qubits commute and thus offer new perspectives on the parallelisability.

[1] Martinez et al.; Nature 534, 516 (2016). [2] Kokail et al.; Nature 569, 355 (2019). [3] Raussendorf et al.; PRL 86, 5188 (2001).

Q 13.65 Mon 16:30 Empore Lichthof

Estimating Error Rates of a Quantum Error Correction Code from its Syndromes — •Thomas Wagner, Martin Kliesch, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf, Institute for Theoretical Physics 3

For near-term quantum devices, a precise characterization of the errors afflicting the device is crucial. Such a characterization can be used in quantum error correction to optimize decoders for the errors at hand, which significantly improves their performance. Information about the errors is usually obtained by benchmarking the device during calibration. However, for some quantum error correction codes it has been recently demonstrated that the syndrome statistics of the code itself also provides information about the errors. This is particularly interesting for online estimation of time varying error rates. In this work, we analytically characterize when parameters of a noise model can be identified from the syndrome statistics alone. Furthermore, we test numerical methods to perform this estimation in practice.

Q 13.66 Mon 16:30 Empore Lichthof

Operation of a microfabricated 2D ion trap array — •Marco Valentini[1], Silke Auchter[1,2], Philip Holz[1], Gerald Stocker[1,2], Kirill Lakhmanskiy[1], Clemens Rössler[2], Elmar Aschauer[2], Yves Colombe[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, University of Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Institut für Quantenoptik und Quanteninformation, 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 11 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 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 ion heating rates in several trapping sites, and report the observation of AC B field-induced shifts in the ions' energy levels. The design of the trap array allows for tuning of the inter-ion distance across the lattice, which we will use to demonstrate motional coupling of ions in neighboring sites.

Q 13.67 Mon 16:30 Empore Lichthof

Charakterisierung einer kryogenen Ionenfallen-Apparatur für skalierbare Quantenlogik — Jonas Schulz, •Max Werner, Janine Hilder, Daniel Pijn, Alexander Müller, Alexander Stahl, Björn Lekitsch, Ulrich Poschinger und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Kryogene Fallen bieten Vorteile für skalierbare Quantenlogik- Anwendungen: Die Reduzierung von Stoßraten mit dem Hintergrundgas erlaubt eine längere Lebensdauer der Ionen und verringertes Rauschen des elektrischen Feldes auf der Fallenoberfläche führt zu reduzierten Heizraten [1]. Wir präsentieren eine neue Apparatur, die mit einem Helium-Flusskryostat und der HOA-2 Oberflächenfalle des Sandia National Laboratory betrieben wird [2]. Die Falle verfügt über 130 Segmente für die Speicherung einer großen Zahl von qubits. Unsere Apparatur ist optimiert, um mit 40Ca+ Spin-Qubits [3] zu arbeiten, die eine reduzierte Sensitivität für mechanische Vibrationen aufweisen [4]. Wir beschreiben technische Besonderheiten des Aufbaus und präsentieren eine detaillierte Charakterisierung der thermischen Eigenschaften. Zudem zeigen wir erste Messungen mit gefangenen Ionen, wie die Ionenlebensdauer, Messungen der Fallenfrequenzen, Heizraten und Mikrobewegungskompensation.

[1] Brownnnutt et al., Rev. Mod. Phys. 87, 1419 (2015)
[2] Maunz, HOA Trap 2.0., SAND-2016-0796R 618951, (2016)
[3] Kaufmann et al,Phys. Rev. Lett. 119, 150503 (2017)
[4] Brandl et al., Rev. Sci. Instrum. 87, 113103 (2016)

Q 13.68 Mon 16:30 Empore Lichthof

Ion Trap Development for Scalable Quantum Computing — Alexander Müller, •Björn Lekitsch, Daniel Pijn, Janine Hilder, Alexander Stahl, Ferdinand Schmidt-Kaler, and Ulrich Poschinger — JGU Mainz, Institute for Physics, Staudingerweg 7, 55128 Mainz, Germany

We present the development of a new symmetric linear Paul trap for trapped-ion quantum computing. Scaling such a system to a few tens of qubits requires a precisely aligned and reliably fabricated ion trap, and also high optical access for laser and detection optics.

We show our work towards such a trap design making use of laser assisted etching of Quartz wafers in combination with physical vapor deposition and electroplating to create individual ion trap chips. We will discuss how two trap chips in combination with structured spacers can be aligned and permanently eutetically bonded together with μm precision using a die bonder. The trap will feature 40 usable electrode segments with an ion electrode distance of 350 μm.

To achieve addressing of single ions we will use both, ion shuttling [1] and individual optical addressing. For this we will equip two distinct trapping segments with full sets of cooling, gate, and detection lasers. One of these segments will feature a high-NA in-vacuum lens for efficient photon counting, and one will feature a high resolution objective for the individual addressing of large ion chains.

[1] D. Kielpinski et al., Nature 417, 709 (2002)

Q 13.69 Mon 16:30 Empore Lichthof

A fast multichannel arbitrary waveform generator for controlling quantum logic experiments based on trapped ion qubits — •Alexander Stahl[1], Björn Lekitsch[1], Janine Hilder[1], Daniel Pijn[1], Alexander Müller[1], Daniel Wessel[1], Matthias Romer[2], Stefan Ulm[2], Frank Ziesel[2], Ferdinand Schmidt-Kaler[1], and Ulrich Poschinger[1] — [1]Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]AKKA DSW GmbH, Magirus-Deutz-Straße 2, 89077 Ulm, Germany

Shuttling ions in segmented radiofrequency traps offers a route to a scalable platform for quantum information processing. We present ongoing work towards extending an existing 80-channel fast multichannel arbitrary waveform generator (mAWG) towards capabilities for quantum error correction. In particular, data transfer protocols, new sequence data format and execution control software and hardware modules are established, which allow for fully generalized branched sequences: Both laser-driven qubit manipulation and ion shuttling operations can be carried out conditioned on in-sequence measurement results. Here, it is crucial to keep processing latencies small as compared to other relevant timescales. The real-time architecture, based on a Zynq system-on-a-chip, includes in-system evaluation and processing of fluorescence measurement data and an interface to a commercial radiofrequency AWG for controlling laser pulses. The architecture also includes a new version of the analog output hardware with improved electrical noise characteristics. The device will be commercialized in collaboration with AKKA technologies.

Q 13.70 Mon 16:30 Empore Lichthof

Using detector tomography to improve the simulation of quantum many-body dynamics on NISQ devices — •Jens Borgemeister — University of Siegen, Germany

On the poster I will present the current state of my work on using detector tomography and other error correction methods to improve the simulation of quantum many-body dynamics on current IBM quantum computers.

Q 14: Precision Measurements and Metrology

Time: Tuesday 11:00–13:00 Location: a310

Q 14.1 Tue 11:00 a310

Entanglement Enhanced Quantum Interferometer — •Raphael Nold, Joel Schmidt, Tobias Linkewitz, Florian Kaiser, and Jörg Wrachtrup — 3. Physikalisches Institut Universität Stuttgart, Stuttgart, Germany

In metrology, interferometers are widely used for precision measurements. The sensitivity of interferometers with classical light is limited by the shot noise. To overcome this classical standard quantum limit one can make use quantum correlated particles. However, the associated detection schemes are generally very complex and slow. To overcome those issues, we present a nonlinear two-photon interferometer were photons pairs are produced by a PPKTP down converting crystal. By passing through this crystal two times we entangle two paths, which leads to interference in the signal-photon intensity (instead of the ordinary photon pair interference). We present our recent results consisting of an enhancement factor above 1.2 and sampling rates up to 20 kHz (enhancement factor of 8000 to comparable attempts [1]). As an application we make use of the measurement speed advantage to investigate the possibility of an entanglement enhanced quantum microscope for cell analysis and a quantum enhanced microphone for making the quantum effect audible.

[1] Ono, T. et al. Nature Communications 4, 2426 (2013)

Q 14.2 Tue 11:15 a310

Complete theory of Ramsey interferometry with squeezing echos — •Marius Schulte, Victor J. Martínez-Lahuerta, Maja S. Scharnagl, and Klemens Hammerer — Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover

We consider a large class of Ramsey interferometry protocols which are enhanced by squeezing and un-squeezing operations before and after a phase signal is imprinted on the collective spin of N particles. We report an analytical optimization for any given particle number and strengths of (un-)squeezing, including experimentally relevant decoherence processes. This provides a complete characterization of squeezing echo protocols, recovering a number of known quantum metrological protocols as local sensitivity maxima, thereby proving their optimality. We discover a single new protocol. Its sensitivity enhancement relies on a double inversion of squeezing. In the general class of echo protocols, the newly found over-un-twisting protocol is singled out due to its Heisenberg scaling even at strong collective dephasing. arXiv:1911.11801

Q 14.3 Tue 11:30 a310

Information content of higher-order intensity correlation measurements about the separation of two equally bright thermal light sources — •Manuel Bojer[1], Anton Classen[1,2], and Joachim von Zanthier[1] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Institute for Quantum Science and Engineering Texas A&M University, College Station, TX 77843, USA

Rayleigh's criterion states that two light sources are unresolvable close to each other if their images, blurred by diffraction, overlap significantly. However, via quantum estimation theory it could be shown that even for small distances there should be in principle information about the source separation available. We here explicitly calculate the quantum Fisher information for two thermal light sources of equal intensities in the far field without an imaging system. Additionally we calculate a lower bound on the Fisher information of various measurement schemes including multi-photon measurements and compare them to the quantum Fisher information. We compare the information content of intensity correlation measurements with a certain numerical aperture to the quantum Fisher information of a smaller with a usual $G^{(1)}$ measurement attainable numerical aperture. We show that the intensity correlation measurements scale very favourable over a large interval of separations due to the bigger numerical aperture, such that they look particularly promising in astronomy for enhancing the resolution of two close-by stars.

Q 14.4 Tue 11:45 a310

Characterization of absorption mechanisms in semiconductors by intensity dependent deflection spectroscopy — •Walter Dickmann[1,2], Tom Götze[2], Mark Bieler[2], and Stefanie Kroker[1,2] — [1]Technische Universität Braunschweig — [2]Physikalisch-Technische Bundesanstalt Braunschweig

We report on a method for the characterization of optical absorption in semiconductors at photon energies below the bandgap energy. We use intensity dependent deflection spectroscopy to measure the optical absorption spatially resolved and to separate the occurring absorption mechanisms. To this end, we take advantage of the different intensity scaling of these mechanisms and extract the material parameters by fitting the intensity dependent absorption to an underlying physical model. The model takes into account relevant processes like phonon-assisted absorption, two-photon absorption and the dynamical Franz-Keldysh effect. These processes affect the refractive index and thus lead to a deflection of the probe beam that is measured. Our method enables a simple but sufficient determination of crucial optical loss properties in various semiconductor systems, e.g. substrates for optical components or solar cells.

Q 14.5 Tue 12:00 a310

Lifetime Measurement of the Cesium $5D_{5/2}$ State with Open Data Availability — •Sebastian Pucher[1,2], Philipp Schneeweiss[1,2], Arno Rauschenbeutel[1,2], and Alexandre Dareau[1,3] — [1]Vienna Center for Quantum Science and Technology, TU Wien – Atominstitut, Stadionallee 2, 1020 Vienna, Austria —

[2]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany — [3]Laboratoire Charles Fabry, Institut d'Optique Graduate School, CNRS, Université Paris-Saclay, 91127 Palaiseau cedex, France

We measure the lifetime of the cesium $5D_{5/2}$ state using a time-resolved single-photon-counting method. We excite atoms in a hot vapor cell via an electric quadrupole transition at a wavelength of 685 nm and record the fluorescence of a cascade decay at a wavelength of 852 nm. We extract a lifetime of the $5D_{5/2}$ state of 1356(9) ns. Our value clearly deviates from the previous experimental literature values [1, 2] but is very well in agreement with a recent theoretical prediction [3]. As we also discuss in the talk, we aim to further improve the transparency of studies of this kind by sharing our measurement outcomes and evaluations via an open-access repository.

[1] D. DiBerardino et al., Phys. Rev. A 57, 4204 (1998)
[2] B. Hoeling et al., Opt. Lett. 21, 74 (1996)
[3] M.S. Safronova et al., Phys. Rev. A 94, 012505 (2016)

Q 14.6 Tue 12:15 a310

Towards testing Local Lorentz Symmetry with ^{172}Yb$^+$ ions — •Chih-Han Yeh, Robin L. Stampa, André P. Kulosa, Dimitri Kalincev, Henning A. Fürst, Laura S. Dreissen, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Deutschland

We report on an experiment for testing Local Lorentz Invariance (LLI) in the electron-photon sector [1] with ^{172}Yb$^+$. Previous experiments did not show an indication of LLI violation to a sensitivity level of $\Delta C_0^{(2)} = 8 \times 10^{-21}$ [2] by comparing two ^{171}Yb$^+$ ion clocks for 45 days. With our approach, we expect a sensitivity of 4×10^{-21} within 24 hours using a single ion and 10 s Ramsey dark time without the need of two operational atomic clocks at the level of 10^{-18} and long measurement times. We plan to test LLI via population fluctuations in the F manifold. To be first-order insensitive to magnetic field noise, we mix the Zeeman substates by dynamical decoupling [3]. To excite the highly forbidden F-state and measure its transition frequency, we used rapid adiabatic passage and demonstrated a reduced uncertainty from 700 kHz [4] to about 10Hz. In the future, we will carry out the LLI test in a multi-ion Coulomb crystal with tailored light fields via a spatial light modulator or a holographic phase plate to reach beyond the 10^{-22} sensitivity level.

[1] V.A. Dzuba et al., *Nature Physics* **12**, 465-468 (2016). [2] C. Sanner et al., *Nature* **567**, 204-208 (2019). [3] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018). [4] M. Roberts et al., *Phys. Rev. Lett.* **78**, 1876 (1997).

Q 14.7 Tue 12:30 a310

Searching for a logarithmic nonlinearity in the Schrödinger equation using free expansion of Bose-Einstein condensates — •Sascha Vowe[1] and Markus Krutzik[1,2] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut Berlin

The time evolution of a quantum mechanical system as described by the Schrödinger Equation (SE) has been shown to yield correct predictions in many, very precise experiments [1]. However, whether the SE can be regarded as a complete description, or rather an linearized approximation of a more general theory, is still an open question.

One of the very first nonlinear additions to the SE which tried to preserve important physical properties such as the separability of non-interacting states was the so called logarithmic SE as proposed by Bialynicki-Birula and Mycielski [2]. We propose novel experiments using the free expansion of Bose-Einstein condensates which, in the light of future long free fall tests on microgravity platforms, are able to put new upper bounds on the strength of this nonlinearity.

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 DLR50WP1432 and DLR50WM1852

[1] S. Lamoreaux, A Review of the Experimental Tests of Quantum Mechanics. Int. J. Mod. Phys. A 07, 6691 (1992)
[2] I. Bialynicki-Birula and J. Mycielski, Nonlinear Wave Mechanics, Ann. Phys. (N.Y.)100, 62 (1976)

Q 14.8 Tue 12:45 a310

Space-borne quantum test of the weak equivalence principle at the 10^{-17} level — •Sina Loriani, Sven Abend, Dennis Schlippert, Christian Schubert, Ernst Maria Rasel, and Naceur Gaaloul — Institut für Quantenoptik and Centre for Quantum Engineering and Space-Time Research (QUEST), Leibniz Universität Hannover, Welfengarten 1, D- 30167 Hannover, Germany

Matter wave interferometry provides a unique access to the interface of quantum theory and gravity and is well suited for probing various aspects of general relativity, ranging from its postulates as the equivalence principle to its implications such as gravitational waves. In this contribution, we present a dedicated satellite mission for testing the universality of free fall to 10^{-17} as proposed for the ESA Voyage 2050 initiative. The theoretical advances and technological maturity that would allow reaching this performance will be highlighted.

We acknowledge financial support from DFG through CRC 1227 (DQ-mat), project B07, CRC 1128 geo-Q, EXC-2123 Quantum Frontiers, the German Space Agency (DLR) with funds provided by the BMWi due to an enactment of the German Bundestag under grant nos. 50WM1641, 50WM1556, 50WM1956, and 50WM0837, as well as by "Niedersächsisches Vorab" through the QUANOMET initiative (QT3) and through "Förderung von Wissenschaft und Technik in Forschung und Lehre" for the initial funding of research in the new DLR-SI Institute. D.S. acknowledges funding by the Federal Ministry of Education and Research through the funding program Photonics Research Germany under contract number 13N14875.

Q 15: Quantum gases (Bosons) II

Time: Tuesday 11:00–13:00 Location: e214

Group Report Q 15.1 Tue 11:00 e214

Bose-Einstein condensates in weak and strong disorder potentials — •Milan Radonjić and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Here we consider different generalizations of a perturbative approach to the dirty boson problem, worked out by Huang and Meng within a Bogoliubov theory [1]. At first, we consider a time-dependent extension by considering how switching on and off a weak disorder potential affects the equilibration of an initially homogeneous BEC and the emergence of a disorder-induced condensate deformation. Afterwards, we work out an approach based on the cumulant expansion method [2] up to second order, that is non-perturbative with respect to disorder and also includes quantum fluctuations. We employ it to study static geometric properties of a harmonically trapped molecular BEC in laser speckle potential [3]. For weak disorder we find quantitative agreement with the Huang and Meng theory, while for strong disorder our theory perfectly reproduces the geometric mean of the experimentally measured transverse widths of the column density profiles. Finally, we compare the non-perturbative results of the second and the third order cumulant expansion approach for a homogeneous Bose gas in impurity disorder.

[1] K. Huang and H. F. Meng, Phys. Rev. Lett. **69**, 644 (1992)
[2] M. Radonjic et al., New J. Phys. **20**, 055014 (2018)
[3] B. Nagler, M. Radonjić, et al., `arXiv:1911.02626`

Q 15.2 Tue 11:30 e214

Atoms trapped by atoms — •Matthias Meister[1] and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, D-89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt (DLR), D-89077 Ulm, Germany

In general, ultra-cold quantum gases are trapped by external magnetic or optical fields to prevent the atoms from expanding. However, in microgravity the different atom-atom interactions available in dual-species Bose-Einstein condensates (BECs) enable us to create a situation, where one atomic species is confined solely by the repulsive interaction with another species.

Our approach [1] is based on a dual-species mixture, where one species fully surrounds the other resulting in a shell-shaped ground state. By selectively trapping only the outer species and raising the inter-species interaction a potential wall forms preventing the inner species from escaping. We have thoroughly studied this process numerically and have analyzed the holding time of this newly formed atom trap as a function of the system parameters. In particular, the quality of the confinement depends on the geometry of the initial state, favoring isotropic setups.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WP1705.

[1] M. Meister, PhD thesis, Universität Ulm, Ulm (2019)

Q 15.3 Tue 11:45 e214

Symmetry-induced many-body quantum interference in chaotic bosonic systems: An augmented Truncated Wigner approach — •Quirin Hummel[1], Peter Schlagheck[1], Denis Ullmo[2], Juan Diego Urbina[3], Klaus Richter[3], and Steven Tomsovic[4] — [1]Université de Liège (Belgium) — [2]Université Paris-Saclay (France) — [3]Universität Regensburg (Germany) — [4]Washington State University (USA)

Although highly successful, the truncated Wigner approximation (TWA) does not account for genuine many-body quantum interference between different solutions of the mean-field equations of a bosonic many-body (MB) system. This renders the TWA essentially classical, where a large number of particles formally takes the role of small $\hbar$. The failure to describe genuine interference phenomena can in principle be overcome by the MB version of the semiclassical van Vleck-Gutzwiller propagator. However, employing the later in its full glory generally eludes a formulation in terms of an initial value problem, one of the major strengths of TWA. Here we consider chaotic bosonic systems with discrete symmetries, where contructive interference leads to significant deviations from TWA [Schlagheck et al., *PRL* **123**, 215302 (2019)]. We show how there the two approaches can be reconciled, combining their strengths in an augmented TWA. We illustrate the validity of our method at pre- as well as post-Ehrenfest time scales in prototypical Bose-Hubbard systems, where it also reveals the existence of additional MB interference effects.

Q 15.4 Tue 12:00 e214

(Non)thermal states of ideal Bose gases contact with external reservoirs: The effect of finite reservoir coupling — •Alexander Schnell[1] and Juzar Thingna[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]IBS Center for Theoretical Physics of Complex Systems, Daejeon, South Korea

The standard framework in which systems in weak contact to external heat-reservoirs are investigated leads to a Lindblad master equation. The underlying assumptions are that the system–reservoir coupling is infinitely weak such that Born-, Markov- and rotating-wave approximation can be performed. For any finite system–reservoir coupling, however, the rotating-wave approximation cannot be performed. Using the standard Born- and Markov approximation one finds a different equation of motion, the Redfield quantum master equation. Contrary to common belief, it was shown that the steady state of this Redfield equation is incorrect already in the first order that goes beyond the Lindblad master equation. Still, there exists a procedure to extract the correct first order correction only from the Lindblad steady state and the Redfield rates [J. Chem. Phys. 136(19),194110 (2012)]. In general, an application of this procedure to quantum many-body systems is out of reach, since it requires knowledge of the full many-body eigenenergies and -states. An exception to this rule are ideal quantum gases. We apply this procedure to the noninteracting Bose gases, both for thermal states and nonequilibrium steady states, and discuss the impact of different bath models.

Q 15.5 Tue 12:15 e214

Non-equilibrium dissipative dynamics of interacting bosons in an optical lattice — •Jens Benary[1], Marvin Röhrle[1], Alexandre Gil Moreno[1], Christian Baals[1,2], Jian Jiang[1], and Herwig Ott[1] — [1]Department of Physics and OPTIMAS research center, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, 55128 Mainz, Germany

We experimentally investigate a driven-dissipative Josephson junction array, realized with a weakly interacting Bose-Einstein condensate loaded in a 1-D optical lattice. Engineered losses on one site act as a local dissipative process. The source of these losses is an electron beam, which we can also use to image the system (SEM) and monitor the losses. Tunneling from the neighboring sites makes up the driving force. Decreasing the tunnel coupling J makes the system cross from a superfluid state to a resistive state. For intermediate values of J, the system shows bistable behavior, with coexistence of a superfluid and an incoherent branch. Studying the individual realizations for single experimental runs we see a digital behavior in the filling of the lossy site, changing from the resistive to the superfluid state within a few tunneling times. We study the dynamics towards a steady state averaged over many experimental runs, finding a critical slowing down and intermediate filling levels of the lossy site, indicating the presence of a non-equilibrium first order quantum phase transition.

Q 15.6 Tue 12:30 e214

Inducing Resonances with Floquet Engineering of Ultracold Scattering — •Christoph Dauer, Axel Pelster, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Magnetic Feshbach resonances are a powerful tool in order to control the scattering length in ultracold gas experiments [1], but are limited to given atomic species or applied magnetic field strengths. Recent studies showed that periodic driving can also induce scattering resonances, but are limited to the simplest inter-particle potentials [2-4]. In this work we consider a more realistic inter-atomic interaction by including an open and a closed channel, as they occur in the description of magnetic Feshbach resonances [5]. We allow for a time-periodic modulation of the inter-channel coupling or the detuning of the channel thresholds and report about the emergence of driving induced scattering resonances. A detailed investigation how resonance frequency and width depend on both driving frequency and strength is performed. With this we obtain predictions for a time-periodic modulation of the magnetic field near a magnetic Feshbach resonance, which are of experimental interest.

[1] C. Chin et al., Rev. Mod. Phys. **82**, 1225 (2010)
[2] D.H. Smith, Phys. Rev. Lett. **115**, 193002 (2015)
[3] A.G. Sykes et al., Phys. Rev. A **95**, 062705 (2017)
[4] S.A. Reyes et al., New J. Phys. **19**, 043029 (2017)
[5] R.A. Duine and H.T.C. Stoof, Phys. Rep. **396**, 115 (2004)

Q 15.7 Tue 12:45 e214

High fidelity two-qubit quantum gate with neutral atoms — •Hui Sun[1,2], Bing Yang[1,2], Hanyi Wang[1,2], Zhen-sheng Yuan[1,2], and Jian-wei Hui[1,2] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

old neutral atoms hold great promise for constructing a quantum device that outperform the classical computer. However, the imperfections of gate operations hinder the implementation of fault-tolerant quantum computing, which requires the operation error to be lower than the threshold 10^{-2}. Here, we report on a high-fidelity two-qubit gate entangling 1250 pairs of neutral atoms in parallel with a operation error of $7(1) \times 10^{-3}$. By improving the precision of controlling the lattice potential, the gate operation driven by the second-order superexchange interaction achieve the same energy scale as the on-site interaction of the Hubbard model. The coherence time is prolonged and the decoherence of entanglement in optical lattice is mainly governed by the intrinsic light scattering. We calibrate the gate fidelity to be 99.3(1)% by measuring spin correlations of the quantum state after multiple gates performed on the atom pairs. Our experiment represents a benchmark towards fault-tolerant quantum computing with neutral atoms.

Q 16: Quantum Information (Concepts and Methods) III

Time: Tuesday 14:00–16:00 Location: e001

Q 16.1 Tue 14:00 e001

Wigner Process Tomography of Unknown Quantum Propagators — •Amit Devra and Steffen J. Glaser — Technische Universität München, Department Chemie, Lichtenbergstrasse 4, 85747 Garching, Germany

We study the tomography of unknown propagators for the spin system in the context of finite-dimensional Wigner representations, which completely characterize and visualize operators using shapes assembled from linear combinations of spherical harmonics. These shapes can be experimentally recovered by measuring the expectation values of the rotated axial tensor operator. Recent works show the general methodology to experimentally recover the shapes for density matrices (ρ) and known quantum propagators (U). This work extends the tomography approach for the unknown propagators. The approach is experimentally demonstrated for one-qubit quantum gates using NMR spectroscopy.

Q 16.2 Tue 14:15 e001

Entropy Production in Open Quantum Systems — •Nico Krause and Heinz-Peter Breuer — Albert-Ludwigs-Universität, Freiburg, Germany

On the basis of a random matrix model we investigate the degree of irreversibility of the dynamics of open quantum systems. Starting from the exact expression for the irreversible entropy production in terms of relative entropy, our central goal is the derivation of a suitable approximate expression which only refers to open system degrees of freedom. This expression depends on a freely choosable state ρ_s^0 of the open system. We present numerical simulations which demonstrate how this state has to be chosen. Furthermore, on the basis of various approximations an analytic derivation of the best choice for ρ_s^0 is developed. The result allows an efficient determination of the entropy production of quantum thermodynamic processes using information theoretical concepts in the regime of weak and intermediate coupling, and in the regime of high and intermediate temperatures.

Q 16.3 Tue 14:30 e001

Exploring the Limits of Open Quantum Dynamics: From Toy Models to Applications — •Frederik vom Ende[1], Gunther Dirr[2], and Thomas Schulte-Herbrüggen[1] — [1]TU Munich, 85748 Garching, Germany — [2]University of Würzburg, 97074 Würzburg, Germany

Which quantum states can be reached by coherently controlling n-level quantum systems coupled to a thermal bath in a switchable Markovian way?

We investigate the reachable sets of coherently controllable open quantum systems with switchable coupling to a thermal bath of arbitrary temperature T. The core problem boils down to studying points in the standard simplex with two types of amenable controls: (i) permutations within the simplex, (ii) contractions by a dissipative semigroup.

Our work focusses on how the solutions to the core problem pertain to the reachable set of the original controlled Markovian quantum system. We completely characterize the case $T = 0$ (amplitude damping) and present partial results for $0 < T < \infty$.

Moreover, one can structure the whole class of normal Lindblad generators in terms of reachability given full unitary control.

Q 16.4 Tue 14:45 e001

An exact approach to quantum non-Markovianity and entropy production in the Caldeira-Legget model — •Simon Einsiedler, Andreas Ketterer, and Heinz-Peter Breuer — Albert-Ludwigs-Universität, Freiburg, Germany

Employing the exact analytical solution of the Caldeira-Leggett model, a paradigmatic model for an open quantum system, we study the non-Markovian quantum dynamics for arbitrary couplings, temperatures and frequency cutoffs. Non-Markovianity is quantified using the Bures metric (fidelity) as distance measure for quantum states. This approach allows us to study quantum memory effects in the whole range from weak to strong dissipation. Furthermore we use a recently proposed expression for the entropy production in non-equilibrium processes to investigate the relation between mutual information and intra environment correlations for a finite number of bath modes.

Q 16.5 Tue 15:00 e001

Multiparticle entanglement detection on sector lengths — •Satoya Imai, Nikolai Wyderka, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen,Walter-Flex-Str. 3, D-57068 Siegen, Germany

Entanglement is one of the most striking phenomena in modern quantum physics. Its emerging properties have played a central role in applications of quantum information. Its generation has also been achieved experimentally, while actual noise effects make us not being sure if a created state is truly entangled. It is thus required to study how to detect entanglement.

We propose a theoretical method for entanglement detection in multiparticle qubit systems. We employ the concept of sector lengths, which can quantify the degree of quantum correlations and have the property of local unitary invariant. We show that the linear combinations of sector lengths can detect genuine multiparticle entanglement.

Q 16.6 Tue 15:15 e001

Positive maps and matrix contractions from the symmetric group — •Felix Huber — ICFO Barcelona, Spain

The study of polynomials that are positive on certain sets has a rich history, going back to Hilbert's seventeenth problem. Here we will look at multivariate polynomials (and more generally, tensor contractions) that have matrices as their variables. We present a family of maps that are positive on the positive cone. This extends the well-known concept of positive maps as used in entanglement theory to the multilinear case. We present connections to polynomial identity rings as well as central polynomials and show some applications in entanglement detection.

Q 16.7 Tue 15:30 e001

Chracterizing multipartite entanglement with moments of random correlations — •Andreas Ketterer[1,2], Nikolai Wyderka[2], and Otfried Gühne[2] — [1]Albert-Ludwigs Universität Freiburg, Freiburg, Germany — [2]Universität Siegen, Siegen, Germany

The trustworthy detection of multipartite entanglement usually requires a number of appropriately chosen local quantum measurements which are aligned with respect to a previously shared common reference frame. The latter, however, can be a challenging prerequisite, e.g., for satellite-based photonic quantum communication, making the development of alternative detection strategies desirable. In order to avoid the distribution of classical reference frames we follow a statistical treatment and show how to characterize multipartite entanglement with moments of correlation functions obtained from locally randomized measurements. To do so, we make use of spherical designs which link entanglement criteria based on moments to ordinary reference frame independent ones. The strengths of our methods are illustrated in various cases, starting with two qubits and followed by more involved multipartite scenarios.

[1] A. Ketterer, N. Wyderka, and O. Gühne, Phys. Rev. Lett. **122**, 120505 (2019)

Q 16.8 Tue 15:45 e001

Activating hidden metrological usefulness — •Géza Tóth[1,2,3,4], Tamás Vértesi[5], Paweł Horodecki[6,7], and Ryszard Horodecki[6,8] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), E-20080 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [5]Institute for Nuclear Research, Hungarian Academy of Sciences, H-4001 Debrecen, Hungary — [6]International Centre for Theory of Quantum Technologies, University of Gdańsk, PL-80308 Gdańsk, Poland — [7]Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdańsk University of Technology, PL-80233 Gdańsk, Poland — [8]Institute of Theoretical Physics and Astrophysics, National Quantum Information Centre, Faculty of Mathematics, Physics and Informatics, University of Gdańsk, PL-80308 Gdańsk, Poland

We consider entangled states that cannot outperform separable states in any linear interferometer. Then, we show that these states can still be more useful metrologically than separable states if several copies of the state are provided or an ancilla is added to the quantum system.

We present a general method to find the local Hamiltonian for which a given quantum state performs the best compared to separable states.

Q 17: Quantum gases (Bosons) III

Time: Tuesday 14:00–16:00 Location: e214

Q 17.1 Tue 14:00 e214

Implanting fermionic ^{6}Li impurities in a Bose-Einstein condensate of ^{133}Cs — •Eleonora Lippi[1], Binh Tran[1], Manuel Gerken[1], Lauritz Klaus[1], Bing Zhu[1,2], Moritz Drescher[3], Tilman Enss[3], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China — [3]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 19, 69120, Heidelberg, Germany

Fermionic ^{6}Li impurities in a ^{133}Cs Bose-Einstein condensate (BEC) realizes a very well controllable version of the Bose polaron, a quasi-particle emulating the Fröhlich polaron problem of solid-state physics. The large mass imbalance between the two species represents the key ingredient to access intriguing aspects of both dynamics and ground-state properties of the Bose polaron. Nevertheless, the large differential gravitational sag between Li and Cs makes its preparation quite challenging.

I will describe the experimental realization of a stable BEC of Cs atoms at high magnetic field (>880 G), where, a broad Feshbach resonance between Li and Cs allows to control the kind and the strength of interactions. Sympathetic cooling has also been observed with Li playing the role of coolant for Cs. A tightly confining movable optical dipole trap at the tune out wavelength of 880.25 nm for Cs allows to confine a cloud of Li in a small volume inside the BEC without imposing additional confinement to Cs.

Q 17.2 Tue 14:15 e214

Bragg scattering of ultracold erbium atoms off a standing wave tuned to near a narrow-line transition — •Roberto Röll, David Helten, Daniel Babik, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Deutschland

We report on the status of an ongoing experiment aiming at investigating the fractional quantum Hall effect with ultracold bosonic erbium atoms by phase imprinting via position dependent optical Raman manipulation. In recent work, we have observed Bragg scattering of an atomic erbium Bose-Einstein condensate off a standing wave tuned into the vicinity of the $J = 6 \to J' = 7$ narrow-line transition (8 kHz natural linewidth) of the erbium atoms near 841 nm wavelength. Despite the small linewidth of this transition, a clear Bragg diffraction signal of the rare earth atoms is experimentally observed. Both current experimental work as well as future plans will be reported.

Q 17.3 Tue 14:30 e214

Witnessing bosonic and fermionic features in quantum transport — •Giulio Amato[1], Alberto Rodriguez[1,2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität-Freiburg — [2]Departamento de Física Fundamental, Universidad de Salamanca

The transport behavior of non-interacting quantum particles through a one-dimensional lattice is governed by the bias between the reservoirs and no clear cut differences between fermionic and bosonic carriers can be observed studying single particle observables. Differences emerge in the two particle observables, due to the underlying discrepancy between fermionic and bosonic many-particle interference phenomena [1]. We explore such differences while providing a method to clearly witness and discriminate the nature of the particles involved in a quantum transport experiment.

[1] F. Schlawin, N. Cherroret and A. Buchleitner, EPL 99, 14001 (2012)

Q 17.4 Tue 14:45 e214

Statistical Transmutation in One Dimension — •Martin Bonkhoff[1], Kevin Jägering[1], Nicholas Sedlmayr[2], Sebastian Eggert[1], and Axel Pelster[1] — [1]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Institute of Physics, M. Curie-Sklodowska University, Lublin, Poland

We compare two different concepts of fractional exchange statistics in one dimension, which have independently been discussed in the literature [1,2]. In the continuum limit both concepts are described by variants of the Lieb-Liniger model, for which we compare their experimental signatures. For instance, we analyze how the Friedel oscillations in the density change with the statistical parameter. The corresponding discretized versions of both concepts are given by the Bose-Hubbard model, where the on-site interaction strength plays the role of the statistical parameter, and by free bosons with a density-dependent Peierl's phase, respectively. Note that such a density dependent Peierl's phase has recently been implemented in optical experiments [3,4]. We study the lattice realizations of both concepts numerically with DMRG calculations and analytically with the bosonization method as well as with the Bogoliubov approximation.

[1] T. Keilmann et al., Nat. Commun. **2**, 361 (2011).
[2] T. Posske et al., Phys. Rev. B **96**, 195422 (2017).
[3] F. Götz et al., Nat. Phys. **15**, 1161 (2019).
[4] C. Schweizer et al., Nat. Phys. **15**, 1168 (2019).

Q 17.5 Tue 15:00 e214

Spectroscopy of dense xenon ensembles - Towards Bose-Einstein condensation of vacuum-ultraviolet photons — •Thilo vom Hövel, Christian Wahl, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Coherent light sources cover wide ranges of the optical spectrum. In the vacuum-ultraviolet regime (VUV, 100 - 200 nm), however, constructing a laser is difficult, as excited state lifetimes scale as ω^3, resulting in the need of very high pump powers to achieve population inversion. We propose an experimental approach for the realization of a coherent light source in the VUV based on Bose-Einstein condensation of photons. In our group, Bose-Einstein condensation of visible photons is investigated using a liquid dye solution as thermalization medium in a wavelength-sized optical microcavity, the latter providing a non-trivial low-energy ground state the photons condense into.

Conveying these principles into the VUV, a replacement for the dye molecules has to be found, as they dissociate under VUV irradiation. We consider xenon atoms a potential candidate, with absorption re-emission cycles on the transition from the ground state ($5p^6$) to the lowest electronically excited state ($5p^5 6s$) for thermalization. We here report on the results of current spectroscopic measurements, investigating VUV line profiles of dense xenon ensembles. Both absorption and emission profiles are presented at pressures up to 180 bar. We also report on VUV spectral profiles of xenon recorded in the liquid phase.

Q 17.6 Tue 15:15 e214

Breaking continuous time-translation symmetrie in a cavity-BEC-system — •Hans Kessler, Jayson G. Cosme, Christoph Georges, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, Germany

We propose an experimental realization of a time-crystal using an atomic Bose-Einstein condensate in a high-finesse optical cavity pumped with laser light detuned to the blue side of the relevant atomic resonance [1]. By mapping out the dynamical phase diagram, we identify regions in parameter space showing stable limit cycle dynamics. Since the model describing the system is time-independent, the emergence of a limit cycle phase indicates the breaking of continuous time-translation symmetry. Employing a semiclassical analysis to demonstrate the robustness of the limit cycles against perturbations and quantum fluctuations, we establish the emergence of a time crystal.

[1] Emergent limit cycles and time crystal dynamics in an atom-cavity system H Keßler, JG Cosme, M Hemmerling, L Mathey, A Hemmerich Physical Review A 99 (5), 053605

Q 17.7 Tue 15:30 e214

Superradiant multimode Floquet polaritons — •Christian Johansen, Johannes Lang, and Francesco Piazza — Max Planck Institut für Physik Komplexer Systeme

Optically trapped driven ultracold atoms in cavities present a highly tunable system for exploring many-body physics. Using near-planar cavities the transversal modes (TMs) are typical distanced by several hundreds megahertz. As such the atoms will dominantly interact only with the resonant TM of the cavity. This interaction between atoms and the cavity gives rise to the well known superradiant instability. New confocal experimental setup have shown that when multiple modes becomes relevant then the nature of the unstable mode changes. In this project we theoretically investigate a system where the pump laser's phase is periodically modulated. This modulation puts higher-order transversal modes closer to resonance in a way that is easily implemented in current near-planar cavity setups Using non-equilibrium field theory we find that this modulation affects both the threshold of the instability and the unstable mode's nature.

Q 17.8 Tue 15:45 e214

Pulse Delay Time Statistics in a Superradiant Laser with Calcium Atoms — •Torben Laske, Hannes Winter, and Andreas Hemmerich — Institut für Laserphysik, Hamburg, Deutschland

Cold samples of calcium atoms are prepared in the metastable $^3P_1$ state inside an optical cavity resonant with the narrow band (375 Hz) $^1S_0 \leftrightarrow {}^3P_1$ intercombination line at 657 nm. We observe a superradiant emission of hyperbolic secant shaped pulses into the cavity with an intensity proportional to the square of the atom number, a duration much shorter than the natural lifetime of the $^3P_1$ state, and a delay time fluctuating from shot to shot in excellent agreement with theoretical predictions [1]. Our incoherent pumping scheme to produce inversion on the $^1S_0 \leftrightarrow {}^3P_1$ transition should be extendable to allow for continuous wave laser operation.

[1] T. Laske, H. Winter, A. Hemmerich, Phys. Rev. Lett. 123, 103601 (2019).

Q 18: Ultracold atoms, ions, and BEC III (joint session A/Q)

Time: Tuesday 14:00–16:00 Location: f303

Invited Talk Q 18.1 Tue 14:00 f303

BECCAL - Quantum Gases on the ISS — •Lisa Wörner[1,2], Christian Schubert[1,3], Jens Grosse[1,2], Claus Braxmaier[1,2], Ernst Rasel[1,2], Wolfgang Schleich[1,4], and the BECCAL collaboration[1,2,3,4,5,6,7] — [1]German Aerospace Center, DLR — [2]University of Bremen — [3]Leibniz University Hanover — [4]University Ulm — [5]Humboldt University Berlin — [6]Johannes Gutenberg University — [7]Ferdinand Braun Institute

BECCAL (Bose-Einstein Condensate and Cold Atom Laboratory) is a bilateral NASA-DLR mission dedicated to execute experiments with ultra-cold and condensed atoms in the microgravity environment of the international space station. It builds on the heritage of NASA's CAL and the DLR founded QUANTUS and MAIUS missions. BECCAL aims to enable a broad range of experiments, covering atom interferometry, coherent atom optics, scalar Bose-Einstein gases, spinor Bose-Einstein gases and gas mixtures, strongly interaction gases and molecules, and quantum information. This contribution gives an overview over the current status of BECCAL and its anticipated capabilities for scientific investigations.

BECCAL is supported by DLR with funds provided by BMWi under Grants Nos. 50WP1700-1706.

Q 18.2 Tue 14:30 f303

Cavity-Enhanced Microscope for Cold Atoms — •Tigrane Cantat-Moltrecht, Nick Sauerwein, and Jean-Philippe Brantut — LQG EPFL, Lausanne, Switzerland

We are setting up a novel type of microscope consisting of an ultra-cold Fermi gas of Lithium 6 atoms in a high-finesse cavity, combined with high-numerical-aperture optics (0.38).

Atoms in the cavity can be detected through their dispersive interaction with light. A second laser beam, focused tightly onto the lithium cloud, locally enhances the coupling of the atoms to the cavity, allowing for non-destructive measurements with sub-micron resolution. Controlling this coupling will also allow to tune the cavity-mediated interactions temporally and spatially, paving the way for novel schemes of quantum simulation of random all-to-all interactions between fermions.

Currently, the core of the optical system has been fully characterized and the vacuum and laser system are operational. I will summarize the important ideas and technical developments behind the design, present the current status of our setup and the next steps towards a working "cavity-microscope".

Q 18.3 Tue 14:45 f303

Delta-kick collimation in dynamic time averaged optical potentials — •Henning Albers[1], Alexander Herbst[1], Ashwin Rajagopalan[1], Wolfgang Ertmer[1], Ernst M. Rasel[1], Dennis Schlippert[1], and The PRIMUS-Team[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]ZARM, Universität Bremen

The precision of atom interferometers highly depends on the center-of-mass motion and the expansion rate of the atomic ensemble. By reducing the latter, systematic effects, e.g. through wavefront aberration, can be reduced. In our setup we perform evaporative cooling in a dynamic time averaged optical dipole trap, generated by spatial modulation of the trapping beams in the horizontal plane, yielding 2×10^5 condensed atoms after 3 s of evaporation. Subsequently we carry out delta-kick collimation (DKC). Beyond pulsed DKC, we use a trapped scheme keeping the atoms captured the entire time. DKC can be performed at any stage of evaporative cooling, thus short-cutting the generation of ultra-cold effective temperatures. In this talk we will show the results of fast BEC production and discuss the DKC results as well as limitations and the perspective of generating up to 10^6 delta-kicked condensed atoms within 1 s.

This work is funded by the DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1641 (PRIMUS), the Federal Ministry of Education and Research (BMBF) through the funding program Photonics Research Germany (contract number 13N14875), and the DFG under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 18.4 Tue 15:00 f303

In-medium bound states of two bosonic impurities in a one-dimensional Fermi gas — David Huber[1], Hans-Werner Hammer[1,2], and •Artem Volosniev[3] — [1]TU Darmstadt, Darmstadt, Germany — [2]ExtreMe Matter Institute EMMI, Darmstadt, Germany — [3]IST Austria, Klosterneuburg, Austria

We investigate the ground-state energy of a one-dimensional Fermi gas with two bosonic impurities. We study the case where impurity and fermions have equal masses, and the impurity-impurity two-body interaction is identical to the fermion-impurity interaction, such that the system is solvable with the Bethe ansatz. For attractive interactions, we find that the energy of the impurity-impurity subsystem is below the energy of the bound state that exists without the Fermi gas. We interpret this as a manifestation of attractive boson-boson interactions induced by the fermionic medium, and refer to the impurity- impurity subsystem as an in-medium bound state. For repulsive interactions, we find no in-medium bound states.

Q 18.5 Tue 15:15 f303

QUANTUS-2 - Towards double Bragg interferometry in microgravity with a collimated BEC — •Merle Cornelius[1], Peter Stromberger[2], Julia Pahl[3], Christian Deppner[4], Sven Herrmann[1], Claus Lämmerzahl[1], and The QUANTUS-Team[1,2,3,4,5,6] — [1]ZARM, Universität Bremen — [2]JGU Mainz — [3]HU Berlin — [4]LU Hannover — [5]Universität Ulm — [6]TU Darmstadt

Quantum sensors based on matter wave interferometry have a wide range of applications for geodesy or tests of fundamental physics. The sensitivity of such precision measurements increase with the interrogation time, thus operating on a microgravity platform is highly beneficial. As a pathfinder for future space missions, the QUANTUS-2 experiment was designed to perform atom interferometry during the free fall time at the ZARM drop tower in Bremen. Our atom chip setup enables rapid BEC production of Rb-87 atoms and utilization of delta-kick collimation to reduce the residual expansion below 100 μm/s. The collimated ensemble, observable after 2 s with a high signal to noise ratio, provides an excellent input source for atom interferometry on long time scales. Here we present first results on ground based interferometric measurements with single Bragg diffraction and a prospect to double Bragg interferometry with a collimated BEC in microgravity with long interferometer times in the range of seconds.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50WM1952.

Q 18.6 Tue 15:30 f303

Observation of First and Second Sound in a Homogeneous Bose Gas — •Timon Hilker[1], Lena Dogra[1], Jake Glidden[1], Christoph Eigen[1], Robert Smith[1,2] und Zoran Hadzibabic[1] — [1]Cavendish Laboratory, University of Cambridge, UK — [2]Clarendon Laboratory, University of Oxford, UK

The existence of two distinct sound velocities is one of the hallmarks of superfluids. In a compressible quantum gas both modes couple to density, which allows us to observe, for the first time, both sound velocities in a moderately interacting ultracold Bose gas. Using a magnetic field gradient, we excite centre-of-mass oscillations of a homogeneous K-39 Bose gas in a three-dimensional box trap, revealing two distinct resonant oscillations. In a microscopic analysis of the mode structure, we find quantitative agreement for the first (and second) sound with the hydrodynamic description of Landau's two-fluid model in terms of in-phase (out-of-phase) oscillations dominated by the thermal (BEC) atoms. We study the speed and the damping of both modes for various interaction strengths and temperatures and investigate in particular the crossover from collisionless to hydrodynamic behaviour above T_C.

Q 18.7 Tue 15:45 f303

Continuous phase transitions in spinor Bose-Einstein condensates with spin-orbital angular momentum coupling — •Yuxiong Duan[1,2], Yuriy Bidasyuk[1], and Andrey Surzhykov[1,2] — [1]Physikalisch–Technische Bundesanstalt, D–38116 Braunschweig, Germany — [2]Technische Universität Braunschweig, D–38106 Braunschweig, Germany

Spin-orbital angular momentum (S-OAM) coupling in Bose-Einstein condensates has been recently realized using Raman coupling with Laguerre-Gaussian beams. A rich phase diagram even at zero temperature is predicted as a result of interplay between spin-orbit coupling, collisional interactions and quantization of angular momentum. In present work we focus on some key features introduced to the phase portrait by quantized angular momentum as this is the main difference of our system from more thoroughly studied linear momentum spin-orbit coupling. We demonstrate how appearance of quantized vortices in the S-OAM coupled system significantly alters the mechanism of phase transitions. In particular we find that the transition between the stripe phase and polarized (or unpolarized) phase is a continuous phase transition. During this process, a vortex molecule appears and contracts towards its center. This unique behavior is absent in the case of linear momentum spin-orbit coupling.

Q 19: Quantum Optics II

Time: Tuesday 14:00–16:00 Location: f342

Invited Talk Q 19.1 Tue 14:00 f342

Interplay of dissipative and coherent processes in engineered quantum systems — •Anja Metelmann — Free University Berlin, Berlin, Germany

The concept of dissipation engineering has enriched the methods available for state preparation, dissipative quantum computing and quantum information processing. Combining such engineered dissipative processes with coherent dynamics allows for new effects to emerge. For example, we found that any factorisable (coherent) Hamiltonian interaction can be rendered nonreciprocal if balanced with the corresponding dissipative interaction. In this talk, we illustrate the basic recipe on how to realize nonreciprocity via reservoir engineering, and show that the dissipative process by itself can yield a purely unitary evolution on one subsystem.

Q 19.2 Tue 14:30 f342

Dynamical phase transitions in a chiral spin chain — •Giuseppe Buonaiuto[1,2], Ryan Jones[1,2], Beatriz Olmos[1,2], and Igor Lesanovsky[1,2] — [1]Institut für Theoretische Physik, Auf der Morgenstelle 14, Universität Tübingen, D-72076 Tübingen, Germany — [2]School of Physics School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom

Open quantum systems with chiral interactions can be realized by coupling atoms to guided radiation modes to waveguides. In their steady state these systems can feature intricate many-body phases such as entangled dark states, but their detection and characterization remains a challenge. We show that the counting statistics of the photons emitted into the waveguide provides a means to detect and characterize the many-body state of a chiral atom chain. Our approach [1] exploits that the guided photons do not only induce interactions between the emitters, but also carry information about their quantum state. This perspective allows to probe intricate dynamical phenomena such as transitions and the coexistence between dynamical phases. In the latter case, entangled states may occur as fluctuations in an intermittent dynamics and are heralded through characteristic features of the time-resolved photon count signal. Our approach also permits to systematically assess the effect of inevitable imperfections, such as the emission of photons into unguided modes

[1]G. Buonaiuto et al., *Dynamical creation and detection of entangled many-body states in a chiral atom chain*, *N. J. P.*, **21**, **11**, 2019

Q 19.3 Tue 14:45 f342

Chiral and correlated atoms driven by non-classical states of light — •Kevin Kleinbeck and Hans Peter Büchler — ITP 3, University of Stuttgart

Many quantum-optical systems consists of a bosonic field (e.g. photons) coupled to an atom-like subsystem, A full descriptions of the boson-atom system is in all but the most trivial cases a cumbersome endeavour, therefore typically just the atomic subsystem is considered, described by the quantum-optical master equation. The master equation enables to the calculations of atomic expectation values and, by the use of input-output relations, expectation values of the bosonic fields. For generic systems, however, correlation functions are inapproachable in this description.

We show, for systems with a chiral interaction (i.e., no backscattering of light) the quantum-optical master equation becomes an exact description, even for correlation functions. For the derivation of the master equation we use the Keldysh formulation, with which we also show how the scattering of non-classical states of light can be included in the master equation. As an example we consider the interaction of light with Rydberg superatoms.

Q 19.4 Tue 15:00 f342

Spinor self-ordering of thermal atoms in an optical cavity — •Luigi Giannelli, Simon Jäger, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

We theoretically analyze the dynamics of cold atomic spins in a single-mode standing-wave cavity as a function of the intensity and relative phase of two transverse lasers, driving the atoms. We identify and discuss the conditions under which stable spatial patterns form, where atomic position and spin phase are correlated. We analyze spin-motion correlations and their dynamics. We finally analyze the properties of the light emitted by the cavity as a method to reveal the state of the system.

Q 19.5 Tue 15:15 f342

Observation of squeezed light from weakly coupled emitters — Jakob Hinney[1], Adarsh Prasad[1], Sahand Mahmoodian[2,3], Klemens Hammerer[2], Arno Rauschenbeutel[4], Samuel Rind[1], Philipp Schneeweiss[4], Anders Sørensen[3], Jürgen Volz[4], and •Max Schemmer[4] — [1]TU Wien, Atominstitut, Austria — [2]Leibniz University Hannover, Germany — [3]Niels Bohr Institute, University of Copenhagen, Denmark — [4]Humboldt-Universität zu Berlin, Germany

We show that the propagation of resonant light through an ensemble of weakly coupled emitters results in the generation of non-classical light. This manifest itself in a change in photon statistics [1]. Here, we present a study of the properties of the transmitted light through the ensemble via measuring the quadrature-squeezing of the transmitted light. The emitters consist of laser cooled Cesium atoms that evanescently couple to the light in the nanofiber. The dependence of the squeezing on input power and input detuning agrees well with theoretical predictions based on [2]. Furthermore, we are able to resolve the squeezing spectrum which reveals the spectral characteristics of the correlated photons that are generated in this process and which lie at the origin of the non-classical nature of the process.

[1] Prasad, A., et al. arXiv 1911.09701 2019
[2] Mahmoodian, S., et al. Phys. Rev. Lett. 2018

Q 19.6 Tue 15:30 f342

Collectively enhanced chiral photon emission from an atomic array near a nanofiber — Ryan Jones[1], Giuseppe Buonaiuto[1,2], Ben Lang[1], Igor Lesanovsky[1,2], and •Beatriz Olmos[1,2] — [1]School of Physics and Astronomy and Centre for the Mathematicsand Theoretical Physics of Quantum Non-Equilibrium Systems,The University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

Emitter ensembles interact collectively with the radiation field. In the case of a one-dimensional array of atoms near a nanofiber, this collective light-matter interaction does not only lead to an increased photon coupling to the guided modes within the fiber, but also to a drastic enhancement of the chirality in the photon emission. We show that near-perfect chirality is already achieved for moderately-sized ensembles, containing 10 to 15 atoms. This is of importance for developing an efficient interface between atoms and waveguide structures with unidirectional coupling, with applications in quantum computing and communication such as the development of non-reciprocal photon devices or quantum information transfer channels.

Q 19.7 Tue 15:45 f342

Transferring entanglement from the spin domain to distinct momentum states — •Fabian Anders, Alexander Idel, Bernd Meyer, and Carsten Klempt — Institut für Quantenoptik, Leibniz Universität Hannover

Many-particle entangled states are commonly prepared in the spin degree of freedom of cold atoms. Within the spin domain entangled states such as the twin-Fock state allow for enhancement of Ramsey measurements beyond the standard quantum limit (SQL). For the application in atom interferometry, however, entanglement between distinct momentum states is needed. We adiabatically prepare twin-Fock states in two spin levels of a spinor Bose-Einstein condensate. By applying a Raman laser coupling we transfer one of the two spin levels to a finite momentum state. I will show first results on the verification of entanglement and present a scheme that allows for gravimetry beyond the SQL.

Q 20: Ultrashort Laser Pulses and Biophotonics

Time: Tuesday 14:00–15:45 Location: f435

Q 20.1 Tue 14:00 f435

Rescattering and space-charge trapping in strong-field photoemission from a macroscopically extruded nanoblade — •Timo Paschen[1], Ryan Roussel[2], Christian Heide[1], Lennart Seiffert[3], Joshua Mann[2], Björn Kruse[3], Philip Dienstbier[1], Thomas Fennel[3], James Rosenzweig[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]UCLA Physics and Astronomy, Los Angeles, CA 90095-1547 — [3]Institut für Physik, Universität Rostock, 18051 Rostock

We demonstrate strong-field-induced photoemission from a nanometer-sharp tungsten-covered silicon blade structure. The pronounced plateau and cut-off features observed in electron energy spectra confirm the presence of elastic rescattering in the enhanced near-fields at the surface of the one-dimensional nanostructure [1,2]. For highest intensities, charge densities in excess of 10^4 electrons per laser pulse and maximum kinetic energies of 1 keV are found. Furthermore, we find a change of photoemission regimes from a field-driven rescattering regime to space-charge limited emission. Accompanying time-dependent Schrödinger equation (TDSE) simulations, reproducing all salient features of the electron spectra, are presented. The above-mentioned observations make this new nanostructure a model system both for the investigation of rescattering on μm scales and light-matter interaction in the space-charge regime.

[1] M. Krüger et al., New J. Phys. 14, 085019 (2012).
[2] S. Thomas et al., New J. Phys. 17, 063010 (2015).

Q 20.2 Tue 14:15 f435

Saturated Femtosecond Stimulated Raman Scattering for Sub-Diffraction-Limited Label-Free Imaging — •Thomas Würthwein[1], Niels Irwin[1], and Carsten Fallnich[1,2] — [1]Institute of Applied Physics, University of Münster, Corrensstraße 2, 48149 Münster, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, Enschede 7500 AE, The Netherlands

We present a scheme for a sub-diffraction-limited Raman microscope. The scheme combines the concept from stimulated depletion microscopy with femtosecond stimulated Raman scattering. The suppression of the Raman signal in a three-beam setup with only two involved wavelength-components was accomplished by the saturation of the Raman scattering. A reduction of the Raman signal of up to 79 % could be measured, with only a single Raman resonance involved. Based on this signal suppression a resolution enhancement by a factor of 2 could be verified in a first proof-of-concept measurement, opening up a pathway towards label-free sub-diffraction-limited Raman imaging.

Q 20.3 Tue 14:30 f435

Characterization of sub-10 fs UV pulses using XPW dispersion scan — •Ayhan Tajalli[1,2], Thomas Kalousdian[3], Martin Kretschmar[3], Sven Kleinert[1,2], Uwe Morgner[1,2,4], and Tamas Nagy[3] — [1]Institute of Quantum Optics, Leibniz Universität Hannover, Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation AcrossDisciplines), Hannover, Germany — [3]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany — [4]Laser Zentrum Hannover e.V., Hannover, Germany

The characterization of ultrashort UV pulses is a rather challenging task, as these pulses are extremely prone to material dispersion and space-time distortions. Moreover, the pulse characterization techniques in this spectral region should adapt another form of nonlinearity than second harmonic or sum frequency generation processes, as the frequency converted signal might lie in difficult spectral ranges. Consequently, the well-known characterization techniques such as FROG have successfully implemented degenerate four-wave mixing processes. However, these techniques suffer from rather bad signal to noise ratio and low sensitivity due to necessity of splitting the wave front. Here, the measurement of 8 fs Deep-UV pulses is performed using a dispersion scan (d-scan) device. We incorporate cross-polarized wave generation, as the nonlinear process. Since d-scan has a single-beam geometry, no beam splitting is necessary, which dramatically improves the sensitivity of the measurement. Accordingly, we can measure Deep-UV pulses with energy as low as 85 nJ with high fidelity.

Q 20.4 Tue 14:45 f435

Optical Kerr Gating with an ultrashort laser pulse — •Dominik Horstmann, Michael Stumpf, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

We implemented an Optical Kerr Gate with switching times on a fs-time scale using an ultrashort laser pulse from the Ti:Sa-laser system PHASER in Düsseldorf. Therefore, the laser pulse is split into an intense gate beam and a less intense signal beam that are focussed on the Kerr medium under a very small angle. While the gate-beam must be well characterized for reproducible operation of the gate, a wide range of optical pulses (intensities, spectral content) can be diagnosed this way. In order to optimize the Kerr Gate we investigated different Kerr media such as fused silica and tellurite glasses. Furthermore, different signal pulses were applied. We show that the arrangement works reliably over a large range of parameters.

Q 20.5 Tue 15:00 f435

Attoseconds on a Chip - Time Domain Measurement of a Near-IR Transient — •Felix Ritzkowsky[1], Mina Bionta[2], Marco Turchetti[2], Yujia Yang[2], Karl Berggren[2], Franz Kärtner[1], and Phillip Keathley[2] — [1]Deutsches Elektronen Synchrotron (DESY) & Center for Free-Electron Laser Science, Notkestraße 85, 22607 Hamburg, Germany — [2]Research Laboratory of Electronics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA

We report on a cross-correlation technique based on perturbation of local electron field emission rates that allows for the full characterization of arbitrary electric fields down to 4 fJ using plasmonic nanoantennas. Plasmonic nanoantennas in combination with ultrafast, few-cycle laser pulses allow for highly non-perturbative experiments that have previously only been demonstrated in the gas phase with high power, low repetition rate laser systems. By exploiting the plasmonic excitation in a metallic nanostructured device, electric field strengths exceeding $\sim$30 GV m^{-1} can be reached at the nanostructure with optical pulse energies of several tens of pJ. This enables sub-cycle attosecond electron bursts to be coherently driven by the electric near field of the plasmon, which we use to sample the near-infrared field-transients at the nanoantenna tip *in-situ*. These results are a strong indicator that this technique can resolve electric fields in amplitude and phase with a potential PHz bandwidth. Such an integrated field-sampler will enable time-domain spectroscopy methods similar to those that have been pioneered in the THz to be applied from the visible through the infrared.

Q 20.6 Tue 15:15 f435

NaYF$_4$:Yb,Er Upconversion Nanoparticles: Analysis of Energy Loss Processes — •Bettina Grauel[1], Christian Homann[2], Christian Würth[1], Ute Resch-Genger[1], and Markus Haase[2] — [1]Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin — [2]Universität Osnabrück

Lanthanide-based upconversion nanoparticles are anti-Stokes emitters with narrow, sharp emission bands in the UV and Vis spectrum, while excited in the NIR. Their luminescence efficiency is affected by lattice defects (especially near the surface), solvent moluecules, surface ligands, and lanthanide doping concentrations, and can vary over several orders of magnitude. By using carefully-designed particles with different sizes, inert shell thicknesses, and doping concentrations, lifetimes and excitation power-dependent quantum yields are recorded and a comprehensive analysis of different energy loss channels is presented. The measurement results are underlined by simulations using a rate equation model system with a nine-level Erbium energy scheme.

Q 20.7 Tue 15:30 f435

Rapidly tunable all-fiber light source for live multicolor coherent Raman imaging — •Maximilian Brinkmann[1,2], Tim Hellwig[1,2], and Carsten Fallnich[1] — [1]Institute of Applied Physics, University of Münster, Germany — [2]Refined Laser Systems GmbH, Münster, Germany

We present multicolor coherent Raman imaging (CRI) with rapid wavelength tuning within only 5 ms between successive images. In order to visualize rapidly evolving or moving samples in coherent Raman imaging (CRI) with high chemical specificity, successive images at multiple vibrational resonances have to be acquired at video-rate speed. Recent approaches to video-rate multicolor CRI, based on parallel laser amplifiers or spectral focusing techniques, allowed wavelength switching on a timescale of (sub)milliseconds, but only across a bandwidth of 300 cm^{-1} at maximum, significantly limiting the chemical specificity. In contrast, the here presented light source is tunable within 5 ms across the wide spectral range between 700 and 3530 cm^{-1}. Therewith, the wavelength can be tuned in a frame-by-frame manner adequate for multicolor image acquisition with up to 100 frames/s. For a first demonstration, we have applied the light source for visualizing lipids and deuterated dimethyl sulfoxide (dDMSO) in mouse ear tissue with coherent anti-Stokes Raman scattering. Rapid switching of the excitation wavelengths to target 2130 cm^{-1} and 2845 cm^{-1} within only 5 ms allowed, without the need for a relative delay adjustment between pump and Stokes beam, to visualize how dDMSO has penetrated from the surface down to about 60 μm deep in the skin.

Q 21: Ultracold Atoms (Trapping and Cooling)

Time: Tuesday 14:00–16:00 Location: f442

Group Report Q 21.1 Tue 14:00 f442

Ultracold atom-ion mixtures in optical light fields — •Pascal Weckesser[1], Fabian Thielemann[1], Daniel Hönig[1], Julian Schmidt[1,2], Kai Lok Lam[1], Markus Debatin[1,3], Leon Karpa[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs-Universität Freiburg, Germany — [2]Laboratoire Kastler Brossel Paris, France — [3]Universität Kassel, Germany

During the past decades ultracold atoms and ions have been two important pillars in atomic and molecular physics. Recently several groups have combined both systems trying to prepare the mixture at ultracold temperatures. Using optical dipole traps for ions [1] provides a new pathway to achieve these ultracold mixtures, as this approach overcomes the intrinsic micromotion heating effects of a conventional Paul trap [2], currently limiting most experiments.

In this talk, we present our experimental setup combining ^{138}Ba^{+} ions with either ^{6}Li or ^{87}Rb atoms. For the former case we present first sympathetic cooling measurements within a Paul trap and discuss the micromotion induced limitation. For the latter case we show how this limitation can be overcome by transferring both atoms and ions in a combined optical dipole trap [3]. These new findings allow the investigation of new phenomena, such as atom-ion Feshbach resonances or the formation of new mesoscopic molecular states.

[1] A. Lambrecht et al., Nature Photonics 11.11 (2017): 704.
[2] M.Cetina et al., Phys.Rev.Lett. 109,253201 (2012)
[3] J. Schmidt et al., arXiv:1909.08352 (2019).

Q 21.2 Tue 14:30 f442

Erste Ergebnisse eines deterministischen Einzelionen-Mikroskops und Ionen-Springbrunnens — •Felix Stopp, Henri Lehec und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Einzelne laser- und sympathetisch mitgekühlte Ionen, die deterministisch aus einer linearen Paulfalle extrahiert werden, erlauben neuartige Methoden der Mikroskopie [1], der Implantation [2] und der Abtastung von Oberflächen zur Untersuchung des Stern-Gerlach-Effekts [3]. Wir präsentieren ein hochstabiles Einzelionen-Mikroskop, um die gesamte Bandbreite der oben genannten Anwendungen zu bearbeiten. Wir stellen die deterministische Extraktion von Ionen mit niedrigen Energien von $\geq$ 40 eV vor. Um Quantenzustände nach Wechselwirkungen auslesen zu können, speichern wir ein einzelnens Ion, welches dann aus der Falle beschleunigt, an einem externen elektrischen Potential reflektiert, wieder in die Falle zurückbeschleunigt und dort gefangen und nachgewiesen wird.

[1] G. Jacob et al., Phys. Rev. Lett. **117**, 043001 (2016)
[2] K. Groot-Berning et al., Phys. Rev. Lett. **123**, 106802 (2019)
[3] C. Henkel et al., New J. Phys. **21**, (2019)

Q 21.3 Tue 14:45 f442

Real-time imaging of single laser-cooled atoms coupled to a nanoscale optical waveguide — Yijian Meng[1], •Christian Liedl[2], Sebastian Pucher[1,2], Arno Rauschenbeutel[1,2], and Philipp Schneeweiss[1,2] — [1]VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria — [2]Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Here, we demonstrate single-atom sensitive imaging of atoms coupled to the evanescent mode of an optical nanofiber in real-time. Degenerate Raman cooling is used to keep the atoms close to the motional ground state of the nanofiber-based trapping sites [1] and to generate the atomic fluorescence signal for imaging. We obtain a signal-to-noise ratio sufficient to identify an atom within 100 ms, allowing us to record movies of single atoms with up to 30 frames during one experimental run.

When, e.g., two atoms are coupled to the nanofiber, their emission into the waveguide can interfere constructively or destructively, depending on the inter-atomic distance. Using our imaging technique, we measure this effect and obtain good agreement with expectations.

Our results enable a new level of control for cold-atom based nanophotonic systems. For example, by post-selecting measurements on a certain number of atoms, also complex light-matter interaction phenomena can be understood atom by atom. Moreover, our findings provide the basis for live, position-resolved feedback onto the experimental system.

[1] Y. Meng et al., Phys. Rev. X 8, 031054 (2018).

Q 21.4 Tue 15:00 f442

Slowing Krypton with Permanent Magnets — •Ergin Simsek, Carsten Sieveke, Pablo Woelk, Daniel Voigt, Malte Peters, and André Lohde — Carl Friedrich von Weizsäcker-Zentrum für Naturwissenschaft und Friedensforschung (ZNF), Universität Hamburg

Krypton is an excellent indicator for the detection of nuclear reprocessing activities and ground water dating. The Atom Trap Trace Analysis (ATTA) promises to be the next generation instrument for measuring the concentration of Krypton isotopes in air and water samples. Here the concentration is determined by measuring the capture rate in a MOT setup. For precooling the atoms to velocities below the MOT capture limit the use of a Zeeman slower is a suitable option. Due to the rapid development of magnetic materials in recent time, permanent magnets are now an attractive alternative to the commonly used magnetic coils for the generation of a strong and precisely shaped magnetic field. Our setup combines a purely optical preparation of metastable Krypton and a Zeeman Slower with transversal magnetic field in Halbach configuration, consisting of several small Neodym magnets. The transversal shape of the field makes it necessary to carefully prepare the atoms into the correct Zeeman sublevel. Here we present a thorough evaluation of our setup with respect to beam forming, metastable generation, state preparation and beam deceleration and analyse its suitability for ATTA.

Q 21.5 Tue 15:15 f442

Evaluation of precooling Krypton for a Zeeman slower — •André Lohde, Ergin Simsek, Carsten Sieveke, Pablo Woelk, and Daniel Voigt — Carl Friedrich von Weizsäcker-Zentrum für Naturwissenschaft und Friedensforschung (ZNF), Universität Hamburg

Krypton is an excellent indicator for the detection of nuclear reprocessing activities and ground water dating. The Atom Trap Trace Analysis (ATTA) promises to be the next generation instrument for measuring the concentration of Krypton isotopes in air and water samples. Here the concentration is measured by measuring the capturing rate in a MOT setup. For precooling the atoms to velocities below the MOT capture limit we use a Zeeman slower. The necessary beam forming is done with a capillary system and transverse laser cooling. The crucial preparation into the metastable state is done optically. We are aiming towards a short Zeeman slower setup so the beam diverges less and the atoms can be trapped more efficiently. Consequently at room temperature a large portion of the atoms are above the capture limit of the Zeeman slower. Liquid nitrogen or thermoelectric precooling increases the number of atoms below the capture limit. Additionally the metastable preparation efficiency is enhanced but also the beam forming by the capillary system is altered. In this talk we present precooling Krypton with both approaches, firstly a thermoelectric cooling and secondly liquid nitrogen cooling. We also give an evaluation based on simulations and measurements on how precooling enhances the efficiencies at different stages of our setup.

Q 21.6 Tue 15:30 f442

Optical trapping and optical delta-kick collimation of atom chip based BECs — •Simon Kanthak[1], Martina Gebbe[2], Matthias Gersemann[3], Sven Abend[3], Ernst M. Rasel[3], Markus Krutzik[1,4], and the QUANTUS team[1,2,3,4,5] — [1]Institut für Physik, HU Berlin — [2]ZARM, Universität Bremen — [3]Institut für Quantenoptik, LU Hannover — [4]Ferdinand-Braun-Institut, Berlin — [5]Institut für Physik, JGU Mainz

Inertial sensors based on matter wave interferometry highly benefit from low expansion rates and extended interrogation times of delta-kick collimated BECs. While atom chip technology allows for fast and efficient BEC production in compact setups, optical dipole traps offer various advantages compared to magnetic traps in the context of controlling the atomic interactions via Feshbach fields or in the reduction of the expansion rates via optical delta-kick collimation with improved harmonic potentials. To combine the benefits of both trap types, we realized a hybrid trap geometry consisting of a single beam dipole trap at 1064 nm in the vicinity of an atom chip. We report on our results of the efficient preparation and transfer of a ^{87}Rb BEC from an atom chip trap into a dipole trap and demonstrate the capability of optical delta-kick collimation.

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 DLR50WP1432 and DLR50WM1852.

Q 21.7 Tue 15:45 f442

An Optical Dipole Trap in a Drop Tower - the Primus Project — •Christian Vogt[1], Marian Woltmann[1], Sven Herrmann[1], Claus Lämmerzahl[1], and The Primus-Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM), 28359 Bremen — [2]Institut für Quantenoptik, LU Hannover

Atom interferometers based on cold atoms have been turned into effective tools to measure weakest forces in the last decades. The sensitivity of these devices scales with the square of interrogation time, normally limited by the time of free fall. Operating atom interferometers in microgravity, like in the drop tower in Bremen, can extend this time from hundreds of milliseconds to several seconds. The leading technology for ultra-cold atoms in microgravity is based on so called atom chips, generating magnetic traps with low power consumption. We focus on an alternative approach based on an optical dipole trap. These come with several advantages like the ability to trap all magnetic sub-states or apply Feshbach resonances. This talk will present recent results from the optical trapping of atoms in microgravity and highlight the benefits of a combined approach including atom chip and dipole trap. The PRIMUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1642.

Q 22: Posters: Quantum Optics and Photonics II

Time: Tuesday 16:30–18:30 Location: Empore Lichthof

Q 22.1 Tue 16:30 Empore Lichthof

Systematic investigations of a 633-nm iodine stabilized diode laser utilizing NICE-OHMS — •Florian Krause, Erik Benkler, and Uwe Sterr — Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

The wavelength 633 nm is common for interferometry and metrology and helium-neon lasers are the prevalent source. Nevertheless, another laser technique is needed, because the technical know-how for building and maintaining helium-neon lasers is vanishing. Iodine stabilized diode lasers at 633 nm using the Noise-Immune Cavity-Enhanced Optical Heterodyne Spectroscopy (NICE-OHMS) technique are promising candidates for an alternative practical realization of the meter.

An extended-cavity diode laser (ECDL) is stabilized to hyperfine lines of $^{127}I_2$. At an averaging time of 1 s this system reaches a short-term frequency instability of 2.4×10^{-12}, which is better than an iodine stabilized helium-neon laser. However, long-term environmental influences disturb the frequency. Systematic investigations of these influences on the absolute frequency were carried out to enable further improvement of the stability. For example the sensitivity on the mismatch between NICE-OHMS modulation frequency f_{mod} and the Free Spectral Range (FSR) f_{FSR} of the cavity was examined. To avoid this mismatch, the modulation frequency f_{mod} is actively locked to the FSR.

For comparison NICE-OHMS signals were simulated, considering the special structure of the iodine spectrum, which consists many overlapping Doppler-broadened hyperfine lines.

Q 22.2 Tue 16:30 Empore Lichthof

Raman laser system for controlling ^{9}Be$^+$ ion qubits — •Simon Rossmann[1], Timko Dubielzig[1], Sebastian Halama[1], Giorgio Zarantonello[1,2], Henning Hahn[1,2], Amado Bautista-Salvador[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universiät Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We operate a cryogenic surface-electrode ion trap setup for $^{9}Be^{+}$ ions. In our project, logic operations are typically carried out using integrated near-field microwave conductors; for bootstrapping and ground state cooling, we employ stimulated-Raman laser pulses. The light for this system is provided via sum-frequency generation of two tunable infrared fiber lasers and a subsequent second harmonic generation. The second harmonic stage is realized using a monolithic cavity design, similar to [1]. The generated 313 nm light is power stabilized and split into two beams. Each of those is frequency shifted in a double-pass AOM setup to realize two beams with a frequency difference of 1083 MHz, corresponding to our qubit transition. To avoid beam pointing fluctuations caused by duty cycle dependent temperature changes within the AOMs [2], we have developed a setup that can cancel this jitter.

[1] S. Hannig *et al.*, Rev. Sci. Instrum. **89**, 013106 (2018)
[2] Yiheng Lin, PhD Thesis, CU Boulder (2015)

Q 22.3 Tue 16:30 Empore Lichthof

Design and Implementation of a Spliced CW-Fiber Amplifier for a Brillouin-LIDAR System — •Benedikt Langfeld, Daniel Koestel, and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, 64289 Darmstadt

In this work, we present a Brillouin-LIDAR system as an alternative to contact-based measuring techniques for the temperature profiles of the oceanic mixed layer (up to 100 m). This is achieved by exploiting the temperature dependent frequency shift of Brillouin-scattered light.

The LIDAR laser system consists of a cw source followed by a series of cw and pulsed fiber amplifiers. An acousto-optic modulator (AOM) between the cw and pulsed stages is used to form pulses with a duration of 10 ns and flexible repetition rate between 1 kHz and 1 MHz. Finally, the pulses are converted into the green spectral range. To measure the frequency shift of the Brillouin-scattered light, we implemented an adjustable edge filter based on an atomic transition of rubidium [1].

To make the operation of the LIDAR system in a helicopter feasible, the system has to be insensitive to vibrations to prevent misalignment of the laser beam. For this reason the system should be completely fiber based. We present a spliced cw-fiber amplifier in a double pass configuration, whose amplified power is used as the basis for the pulse generation by the AOM.

[1] A. Rudolf and T. Walther, Opt. Lett. **37**, 4477-4479 (2012)

Q 22.4 Tue 16:30 Empore Lichthof

Monolithic Fiber Fabry Perot cavities for spectroscopy — •Florin Hemmann, Carlos Saavedra Salazar, Madhavakkannan Saravanan, Hannes Pfeifer, Deepak Pandey, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik, Rheinische Friedrich-Wilhelms-Universität Bonn, Deutschland

Fiber Fabry Perot cavities (FFPC) have emerged as an interface to enhance light-matter interactions [1]. Fabricating versatile and robust fiber cavities as required for most applications however remains a challenging task. By combining fiber guiding glass ferrules with piezo elements we develop a monolithic FFPC design that exhibits high passive stability and large locking bandwidths combined with a tunability over a full free spectral range.

One promising application of these stable resonators is as a miniaturized system for spectroscopy of gases. We demonstrate the ability to determine various oxygen concentration levels in a prototype experiment.

[1] D. Hunger. New Journal of Physics 12. 065038 (2010)

Q 22.5 Tue 16:30 Empore Lichthof

A laser sytem for sideband cooling of single $^{9}Be^{+}$ ions in a Penning trap — •Julian Pick[1], Johannes Mielke[1], Teresa Meiners[1], Matthias Borchert[1,3], Frederik Jacobs[1], Amado Bautista-Salvador[1,2], Juan M. Cornejo[1], Malte Niemann[1], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch Technische Bundesanstalt, Braunschweig — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN

The BASE collaboration pursues the goal to perform high precision measurements of the (anti-)proton g-factor as tests of CPT invariance in the baryonic sector. Quantum logic inspired cooling and readout techniques based on a co-trapped laser-cooled $^{9}Be^{+}$ ion can potentially be applied to contribute to these measurements. However, for many of the proposed methods it is desirable for the ion to be in the motional ground state.

Here we present a Raman laser system for sideband cooling of single $^{9}Be^{+}$ ions in a Penning trap. The system consists of three tunable cw infrared fiber-lasers and generates two beams at 313 nm via sum frequency generation and subsequent second harmonic generation. The Raman beams need to bridge the 140 GHz qubit splitting at a magnetic field of 5 T. Phase coherence is ensured by implementing an optical phase-locked loop for the infrared fiber-lasers.

We present recent progress in the implementation and characterization of the laser system, as well as the concepts for the integration of this system into the experiment.

Q 22.6 Tue 16:30 Empore Lichthof

A cw-OPO system for ultimate M-IR frequency resolution — •Ulrich Eismann[1], David B. Foote[2], Matt Cich[2], Walter Hurlbut[2], Felix Rohde[1], and Chris Haimberger[2] — [1]TOPTICA Photonics AG, Lochhamer Schlag 19, D-82166 Graefelfing, Germany — [2]TOPTICA Photonics, Inc., 5847 County Rd. 41, Farmington, NY 14425, USA

Continuous-wave optical parametric oscillators (cw-OPOs) are versatile light sources for quantum technologies. They deliver tunable narrow-band light in a large wavelength range, and output powers ranging from high-flux heralded photon sources up into the multi-10-Watt class have been demonstrated.

Here, we present a commercial cw-OPO (TOPTICA DLC TOPO) emitting up to 4 W in the 1.45–4.0 μm range and results of frequency referencing. The absolute accuracy of our current scheme is in the low 10^{-3} cm^{-1} range ($\approx$ 100 MHz). It is given by the accuracy and resolution of the wavelength meter, and the abundance of nearby reference peaks. Using a frequency comb as a reference, ultimate accuracies can be achieved. At its extreme, the scheme allows phase-coherent links between the M-IR and other wavelength ranges of choice [1]. We will discuss locking of the system to a commercial comb system DFC CORE.

[1] E. V. Kovalchuk et al., Optics Letters 30, 3141-3143 (2005).

Q 22.7 Tue 16:30 Empore Lichthof

Atom Trap Trace Analysis: An ultra-sensitive spectroscopy technique for dating of environmental tracers — •Julian Robertz[1], Lisa Ringena[1], Maximilian Schmidt[1,2], Niccolo Rigi-Luperti[1], Florian Sandel[1], Jeremias Gutekunst[1], Arne Kersting[2], Yannis Arck[2], David Wachs[2], Annabelle Kaiser[2], Werner Aeschbach[2,3], and Markus Oberthaler[1] — [1]Kirchhoff Institute for Physics, Heidelberg, Germany — [2]Institute for Environmental Physics, Heidelberg, Germany — [3]Heidelberg Center for the Environment, Heidelberg, Germany

Environmental tracers serve as an important source of information in a wide range of natural sciences. Due to the low relative abundance of some of these tracers an ultra-sensitive detection technique is necessary. In the case of the environmental tracer ^{39}Ar the Atom Trap Trace Analysis (ATTA) allows us to measure relative abundances in the range of 10^{-16}. The isotopic shift in the resonance frequency together with multiple resonant scattering processes grants perfect selectivity. Single atoms are captured and identified in a magneto-optical trap (MOT), while the huge background of abundant isotopes remains unaffected.

This ultra-sensitive spectroscopy technique was successfully used to study groundwater, lake, ocean and ice samples. In order to stretch the available dating range to younger ages, first steps regarding ATTA with ^{85}Kr have been taken. Preliminary investigations for the new laser system will be presented.

Q 22.8 Tue 16:30 Empore Lichthof

High-precision spectroscopy enhanced with squeezed light — •Jonas Junker[1,2,3], Dennis Wilken[1,2,3], Elanor Huntington[4], and Michèle Heurs[1,2,3] — [1]Max Planck Institute for Gravitational Physics, and Institute for Gravitational Physics, Germany — [2]QuantumFrontiers — [3]PhoenixD — [4]Centre for Quantum Computation & Communication Technology and Research School of Engineering, The Australian National University, Australia

Highly sensitive spectroscopic measurements require suppression of intrinsic noise within the apparatus. At low frequencies, active control can reduce dominant technical noise sources down to the fundamental shot noise limit. In addition to noise reduction, the achieved signal-to-shot-noise ratio can also be improved by increasing the laser power, at least up to the damage threshold of the probe. Here, we demonstrate an alternative approach that improves the signal-to-shot-noise ratio without increasing the laser power. Technical noise sources can be avoided by phase modulating the signal. In order to additionally decrease the shot noise, the signal is superimposed with high-frequency non-classical states of light. The goal is to detect small phase or amplitude signals at kHz frequencies that can be masked by technical noise sources, but also by shot noise. With our approach, we can uncover these signals without increasing the laser power. We present experimental results and the theoretical derivations supporting them. Our proposed technique is interesting for such applications as high-precision cavity spectroscopy, in particular for explosive trace gas detection where the specific gas may set a limit for the used laser power.

Q 22.9 Tue 16:30 Empore Lichthof

Tunable vacuum ultaviolet laser setup for first nuclear spectroscopic measurements on thorium — •Philip Mosel, Uwe Morgner, and Milutin Kovacev — Institut für Quantenoptik, Cluster of Excellence PhoenixD and QuantumFrontiers, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

The metastable transition from the nuclear ground state to the first excited state of the thorium isotope ^{229}Th with a calculated lifetime in the range of 10^{-4}s [1] is a promising candidate for the realization of the first optical nuclear clock. Due to its extraordinarily low excitation energy of about 8.26 eV, corresponding to a wavelength of about 150 nm [2], it is reachable by laser systems in the vacuum ultraviolet (VUV). Here we present a laser system based on four-wave mixing in Xenon of a tunable pulsed Ti:Sapphire and its third harmonic. This scheme allows for an efficient fifth harmonic generation in the VUV (140 - 160 nm). The system provides a suitable source for the precisely determination of the transition energy by laser-based conversion electron-Mössbauer spectroscopy (CEMS) in thin layer of neutral ^{229}Th atoms [3]. The exact knowledge of the excitation energy is crucial for laser spectroscopy of individual thorium ions in Paul traps and for the development of an optical single ion nuclear clock.

[1] N. Minkov and A. Palffy, Phys. Rev. Lett. **118**, 212501 (2017).
[2] B. R. Beck *et al.*, Phys. Rev. Lett. **98**, 142501 (2007).
[3] L. von der Wense *et al.*, Phys. Rev. Lett. **119**, 132503 (2017).

Q 22.10 Tue 16:30 Empore Lichthof

Cryogenic sapphire cavities as ultrastable optical frequency references for improved laboratory test of Lorentz invariance — •Erich Günter Leo Pape, Achim Peters, and Evgeny Kovalchuk — HU Berlin AG QOM, Newtonstraße 15, 12489 Berlin

We present the latest updates on our cryogenic sapphire cavities as ultrastable frequency references, which will be used for an improved laboratory test of Lorentz invariance in electrodynamics by testing the isotropy of the speed of light at the 10^(-20) level. We integrated two cavities into out closed-cycle cryostat at 4K with free beam propagation and active beam point stability control and with fiber-coupled beam propagation using fiber phase noise compensation and detection within the cryostat to minimize effects of residual amplitude modulation as well as to improve SNR.

Q 22.11 Tue 16:30 Empore Lichthof

Cross-Phase Modulation Artifacts in Femtosecond Stimulated Raman Scattering — •Thomas Würthwein[1], Niklas M. Lüpken[1], and Carsten Fallnich[1,2] — [1]Institute of Applied Physics, University of Münster, Corrensstraße 2, 48149 Münster, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, Enschede 7500 AE, The Netherlands

Coherent Raman scattering techniques, such as femtosecond stimulated Raman scattering (FSRS), show a great potential for a number of applications due to an enhanced signal-strength in comparison to spontaneous Raman scattering. FSRS is free of a non-resonant background but is affected by two-photon absorption as well as cross-phase modulation (XPM) and temperature-induced refractive index changes. The resulting artifacts in SRS become relevant for high pulse energies and ultrashort pulses, necessary for super-resolution experiments. Here, we present a systematic study in order to investigate the influences of XPM on FSRS in the regime of high pulse energies by varying the most crucial parameters for XPM, namely the pulse duration, the temporal overlap, the peak intensity, and the nonlinear refractive index of the sample.

Q 22.12 Tue 16:30 Empore Lichthof

Deep learning phase reconstruction from dispersion scan traces — •Sven Kleinert[1,2], Ayhan Tajalli[1,2], Tamas Nagy[3], and Uwe Morgner[1,2,4] — [1]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering Innovation Across Disciplines), Hannover, Germany — [3]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Straße 2a, 12489 Berlin, Germany — [4]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany

For applications of femtosecond laser pulses the knowledge of their temporal shape plays a crucial role. Many different techniques for measuring these information have been developed during the last decades. The recently proposed dispersion scan (d-scan) is a simple technique to fully characterize ultrashort pulses. The reconstruction of the temporal shape of the pulses from a d-scan trace is an inverse problem as it is usually the case for the characterization techniques, which benefit from an inherent redundancy in the measurement. Conventionally, time-consuming optimization algorithms are used to solve these inverse problems. Here, we show the retrieval of femtosecond pulses from d-scan traces using a deep neural network. This neural network is trained with artificial and noisy dispersion scan traces from randomly shaped pulses. After the training, the phase reconstruction takes only 16 ms enabling video-rate pulse characterization. This retrieval shows a great tolerance against noisy conditions, delivering reliable retrievals from traces with up to 20% of noise.

Q 22.13 Tue 16:30 Empore Lichthof

Near-field phase diagnostics of intense ultrashort laser pulses — •Sergej Poplavski, Bastian Hagmeister, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

Intense ultrashort laser pulses with pulse durations in the 10 fs regime have gained increasing relevance in experimental physics and accomplished applicability in many different fields; from a mere diagnostics tool over time resolution in ultrashort physics to next generation particle accelerators. Yet even small aberrations cause large uncertainties of the spatial and temporal intensity in the focal region of ultrashort laser pulses. Hence the precise knowledge of the pulse shape is of utmost importance for reproducible and reliable experiments.

Since diagnostics in the focus is impractical and often even unfeasible, we present an indirect approach to focus diagnostics: The field is characterized with respect to its amplitude and phase in the near-field with spectral and spatial resolution, allowing a conclusion onto the pulse's properties in the focus. We compare methods for retrieving the required data and discuss the calibration procedure and the reliability of the transformation from the near-field to the far-field.

Q 22.14 Tue 16:30 Empore Lichthof

Gap-size dependence of optical near-fields in a variable nanoscale two-tip junction — •Jonas Heimerl, Takuya Higuchi, Maximilian Ammon, M. Alexander Schneider, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Optical field enhancement of metallic nanostructures under illumination with near-infrared fs-laser pulses enables nonlinear electron emission with comparably low pulse energies. When two nanostructures are brought into nanometer vicinity, the optical near-fields of both structures couple and the field is even more enhanced. Here we demonstrate an ambient-conditioned STM-setup allowing us to align two metal needle tips on the sub-nanometer scale facing each other. By measuring the photocurrent as a function of the gap size, we can retrieve the peak electric field at the tip apices. We observe field enhancement up to 15.9 at one tip apex, being four-times larger than for a single tip. Moreover, by scanning the laser focus near this gap junction, we show that field enhancement is well localized to the gap junction, which we can separate from mainly thermal expansion effects visible when we illuminate the tip shank.

Q 22.15 Tue 16:30 Empore Lichthof

Investigations toward diffraction imaging by High Harmonics — •Kai Lennard Rose, Dirk Hemmers, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

High Harmonic Generation (HHG) by ultrashort laser pulses is a useful way of generating spatially coherent directed radiation in the vacuum and extreme ultraviolet (VUV to XUV) spectral range. Especially the so-called water window (2.3 nm - 4.4 nm) with its high transmission by oxygen and strong absorption by carbon is an advantageous region for imaging of organic materials and is often used with other radiation sources. Applying harmonic radiation in this range promises new opportunities by employing its coherence properties with phase-related diagnostic techniques. We performed feasibility studies on diffraction imaging of μm-scale test objects by harmonics in the micrometer-range produced by the few-cycle Ti:Sa-system PHASER in Düsseldorf. First experimental results together with analytical and numerical simulations are presented. These results show that the coherence of the harmonic radiation carries a large potential for further developments.

Q 22.16 Tue 16:30 Empore Lichthof

Parametric studies of High Harmonic Generation in gases in the few-nm range — •Natascha Thomas, Dirk Hemmers, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

High Harmonic Generation (HHG) in gaseous media is a convenient technique for generating coherent, laser-like radiation ranging from the VUV to the soft X-ray regime. Specific interest lies on the so-called water window (wavelengths between 2,3 nm and 4,4 nm), where oxygen is transparent and carbon highly absorptive with important applications in biology and medicine. Previously, this range has been accessed via driving lasers in the IR. We present elaborate HHG parameter studies using the PHASER few-cycle Ti:Sa-system in Düsseldorf, which aim at optimizing the harmonic output in the few-nm range. We show how the spectral cutoff can be shifted systematically by combined variation of multiple parameters, most of all the precise optimization of intensity in the interaction region by means of our new pulse attenuator.

Q 22.17 Tue 16:30 Empore Lichthof

Third harmonic generation in thin film layers — •David Zuber[1,2], Holger Badorreck[2,3], Morten Steinecke[3], Marco Jupe[2,3], and Uwe Morgner[1,2,3] — [1]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering Innovation AcrossDisciplines), Hannover, Germany — [3]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany

Cascaded third harmonic generation (THG) of NIR lasers is a state of the art technique for the generation of ultrashort pulses in the UV spectral region. This approach suffers from several obstacles, mainly the high complexity and phasematching restraints. For many applications, both problems can be circumvented by using direct THG from thin films. THG from thin films is known to be strongly dependent on the thickness of the layer. Here, these thickness dependence is experimentally studied by measuring the backward and forward direction THG from thin layers on top of a substrate. The samples were specially manufactured as gradient layers with continously varying thickness ranging from a few nanometers to a few micrometers. The results are compared to simulations with and without internal interference effects to determine regimes, where those effects have to be included to predict the THG correctly. The results will be used to estimate the $\chi^{(3)}$ value of the layers materials. Furthermore, the influence of the substrate and the surrounding medium on the THG will be studied by using different substrate materials and surrounding gasses.

Q 22.18 Tue 16:30 Empore Lichthof

Electron Emitter Arrays on a Chip — •Constantin Nauk, Constanze Gerner, Philip Dienstbier, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen- Nürnberg (FAU), 91058 Erlangen

High-density gold tip arrays are promising candidates for femtosecond laser electron emission, suitable for a variety of applications. Single sharp tips with small radii (5-10nm) have proven good field emission characteristics such as high brightness and coherence but lack large currents. We present the current status of sharp gold tips (radii below 20nm) processed in array arrangements on a chip to face this issue. Among others, these cathodes could serve as emitters in photonics-based particle accelerators. We show the fabrication and characterization of 26 gold tips/μm^2 as well as first femtosecond laser-driven emission experiments.

Q 22.19 Tue 16:30 Empore Lichthof

Investigation of time dynamics of atom-light interaction in the superstrong coupling regime — •Martin Blaha[1], Aisling Johnson[1], Philipp Schneeweiss[2], Arno Rauschenbeutel[2], and Jürgen Volz[2] — [1]TU Wien, 1020 Wien, Austria — [2]HU Berlin, 12489 Berlin, Germany

We report on the observation of superstrong coupling between a cloud of cold atoms and a 50-m long nanofiber-based fiber ring resonator[1]. This novel regime of light-matter coupling is reached when the collective coupling strength between a cloud of laser-cooled Cesium atoms and the light field exceeds the free spectral range (FSR) of the resonator leading to simultaneous strong coupling of the atoms with more than one longitudinal resonator mode[2].

In a next step, we investigate the dynamics of the atom-resonator interaction in this regime. For this we probe the system with a few nanosecond long pulse shorter than the dynamical time scales in the resonator. We monitor the time-dependent response of the coupled system and observe a direction-dependent and collective decay in forwards direction while the dynamics in backwards direction is equivalent to the decay time of a free-space atom.

[1] A. Johnson et al., arXiv:1905.07353(2019).
[2] D. Meiser et al., Phys. Rev. A 74, (2006).

Q 22.20 Tue 16:30 Empore Lichthof

Fiber based Mode Matching for Fabry-Pérot Cavities — •Pritom Paul, Timon Eichhorn, and David Hunger — Physikalisches Institut (PHI), Karlsruher Institut für Technologie, Wolfgang-Gaede-Str.1, 76131 Karlsruhe, Germany.

Fiber Fabry-Pérot Cavities(FFPC) with micro mirrors fabricated on the end facets of optical fibers combine a high finesse with a small mode volume and full tunability [1]. Due to these properties, FFPCs can be beneficially used e.g. for sensing of nanoparticles, cavity optomechanics, and for solid-state based quantum information. For all applications, efficient excitation and collection of light in the cavity mode with a single mode fiber is desirable. However, restricted spatial mode matching substantially lowers the overall coupling efficiency for fully fiber-based FFPCs. To overcome this problem, the aim of this work is to fabricate a fiber based mode matching assembly. As it was shown for fiber cavities targeting large mirror separations e.g. for ion trap experiments, splicing together a single mode, a multimode and a graded-index fiber can serve as mode matching optics [2]. Here, we adapt this approach for FFPC with minimized mode volume and mode cross section as desired for e.g. experiments with solid-state quantum emitters. We report the current status of the project.

[1] Hunger, D. et al. A Fiber Fabry-Pérot with High Finesse, New Journal of Physics 12, 065038 (2010).
[2] Gulati, G K. et al. Fiber Cavities with Integrated Mode Matching Optics, Scientific Reports 7, 5556 (2017)

Q 22.21 Tue 16:30 Empore Lichthof

Towards Cavity-Enhanced Spectroscopy of Single Europium Ions in Yttria Nanocrystals — Timon Eichhorn[1], Kelvin Chung[1], Sören Bieling[1], •Tobias Krom[1], Bernardo Casabone[2,3], Julia Benedikter[1,3,4], Thomas Hümmer[3,4], Alban Ferrier[5,6], Philippe Goldner[5,6], Hugues De Riedmatten[2,7], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]ICFO-Institut de Ciencies Fotoniques — [3]Max-Planck-Institut für Quantenoptik — [4]Fakultät für Physik, Ludwig-Maximilians-Universität — [5]Université PSL, Chimie ParisTech, CNRS — [6]Sorbonne Université — [7]ICREA-Institució Catalana de Recerca i Estudis Avançats

A promising approach for realizing scalable quantum registers lies in the efficient optical addressing of qubits in a solid state host. Within the EU Quantum Flagship project SQUARE we tackle this problem by coupling the fluorescence of Eu^{3+} ions doped into Y_2O_3 nanoparticles (NPs) to a high-finesse fiber-based Fabry-Pérot microcavity. As a first step towards efficient readout of single rare earth ions, we present cavity-enhanced spectroscopy measurements of a few europium-ions as published in New J. Phys. **20** (2018) 095006. We furthermore report our efforts towards Purcell-enhanced single ion detection with high-resolution excitation spectroscopy. Therefore, we are currently setting up a reference cavity to narrow down the laser linewidth. Simultaneously we are working on a new method to place single NPs inside a passively stable, low-temperature fiber-fiber microcavity.

Q 22.22 Tue 16:30 Empore Lichthof

Overlapping modes effects in X-ray cavity QED — •Dominik Lentrodt, Kilian P. Heeg, Christoph H. Keitel, and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

In recent years, a new platform for quantum optics has emerged: nuclear cavity QED, where Mössbauer nuclei are placed in nano-cavities and driven by hard X-ray sources. Due to the unique properties of these nuclei, such as exceptionally long decoherence times, and the high photon energies of hard X-rays, this system constitues one of the highest quality quantum systems in nature, with possible applications ranging from metrology and precision spectroscopy to materials and even quantum information science. In this poster, we show novel cavity QED effects that arise in this system due to the overlapping modes stucture of the cavities in use, and how to harness them for quantum optical purposes. In particular, we outline how these effects can be described theoretically within the framework of ab initio few-mode theory [1], which provides access to new interpretations of the collective Lamb shift [2], which was famously discovered in this system, and an EIT phenomenon [3], which is promising with regards to achieving non-linear effects at current and upcoming X-ray facilities [4].

[1] Lentrodt & Evers (2018) arXiv:1812.08556 [quant-ph] [2] Röhlsberger et. al. *Science* **328** 5983 (2010), Heeg et. al. *Phys. Rev. Lett.* **114** 207401 (2015) [3] Röhlsberger et. al. *Nature* **482** 199203 (2012), Heeg & Evers *Phys. Rev. A* **91** 063803 (2015) [4] Heeg, Keitel & Evers (2016) arXiv:1607.04116 [quant-ph]

Q 22.23 Tue 16:30 Empore Lichthof

Towards cavity-enhanced single ion spectroscopy of Yb^{3+}:Y_2O_3 — •Jannis Hessenauer[1], Sören Bieling[1], Tobias Krom[1], Philippe Goldner[2,3], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Physikalisches Institut — [2]Université PSL, Chimie ParisTech, CNRS — [3]Sorbonne Université

Rare-earth ions are promising candidates for optically addressable spin qubits, owing to their long optical and spin coherence times. Yb^{3+} is of special interest among the rare earth ions due to its simple energy level scheme, comparably strong transition oscillator strength and its paramagnetic properties. An efficient spin-photon interface for quantum information technology requires the coupling of single ions to a high finesse cavity, which serves to enhance the transitions via the Purcell effect and to increase the emission into a single, well-collectible cavity mode. The goal of our experiment is to address single Yb^{3+} ions in Y_2O_3 nanoparticles (NPs) by placing them inside a high finesse fiber based Fabry-Pérot cavity at cryogenic temperatures. To characterize the nanoparticles, we perform ensemble spectroscopy in an all-fiber setup. For quick sample preparation, we investigate picking and placing of single NPs on the end facet of optical fibers. An external reference cavity is set up to stabilize the laser linewidth below the homogenous linewidth of Yb^{3+}, which will enable selective addressing of single Yb^{3+} ions.

Q 22.24 Tue 16:30 Empore Lichthof

High finesse fiber cavity as a light matter interface for quantum optics application — •Patrick Maier, Stefan Häussler, Gregor Bayer, Richard Waltrich, and Alexander Kubanek — Institut für Quantenoptik, Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm

Quantum network applications based on entangled photons suffer from losses over large distances as well as classical applications. To overcome those losses quantum repeaters based on solid-state quantum emitters offer one promising solution. In particular color centers in diamond like the silicon vacancy (SiV^-) and germanium vacancy (GeV^-) in diamond and defect centers in tailored 2D materials are favourable due to their outstanding optical properties.

We demonstrate the feasibility of experiments with high rate of coherent photons using a coupled system of a high quality Fabry Perot microcavity and different color centers. We furthermore investigated and compared different color center host materials covering different spectral regions. As a next step the cavity setup is upgraded to a bath cryostat compatible design, especially considering stability and tuneability of the system.

Q 22.25 Tue 16:30 Empore Lichthof

Implementation of Optical Tweezers in a Small Scale Cavity-QED Setup — •Saibin Zhou, Bo Wang, Nicolas Tolazzi, Christopher Ianzano, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

Optical tweezers with the capability to manipulate single atoms have recently been achieved[1][2]. Here we seek to implement the microscopic optical tweezers method in our strongly-coupled atom-cavity system and manipulate the spatial position of individual ^{87}Rb atoms trapped in an optical lattice. To have control over the exact locations of atoms within the cavity is crucial, as the coupling strength between the electromagnetic field mode and the atom depends heavily on position. This is especially important in our case where we have a strong atom-cavity coupling on both the D_1 and D_2 lines of ^{87}Rb, requiring an independent longitudinal mode of the cavity for each transition[3]. Having precise control over the position of an atom within the cavity would therefore allow for tuning of each coupling strength independently. It also provides the ability to manipulate multiple atoms individually and simultaneously. Compared to a tweezers setup in free space, our system has very limited optical access due to the proximity of the Fabry-Pérot mirrors. Therefore, we present a special design for our optical tweezers system together with detailed results.

[1] Daniel Barredo et al., Science, **354**, 1021(2016).
[2] Manuel Endres et al., Science, **354**, 1024(2016).
[3] Christoph Hamsen et al., Nature Physics, **14**, 885(2018).

Q 22.26 Tue 16:30 Empore Lichthof

Coupling a single trapped atom to a WGM microresonator — •Luke Masters[1], Elisa Will[2], Michael Scheucher[2], Jürgen Volz[1], and Arno Rauschenbeutel[1] — [1]Department of Physics, Humboldt-Universität zu Berlin, Germany — [2]Vienna Center for Quantum Science and Technology, TU Wien - Atominstitut, Austria

Strongly coupling single quantum emitters to the guided light field of Whispering-gallery-mode (WGM) resonators allows one to reach the strong coupling regime [1]. Furthermore, this setting provides chiral, i.e. propagation direction-dependent, light-matter coupling which can be employed for realising novel quantum devices [2, 3]. However, trapping atoms close to such resonators has not yet been demonstrated.

We demonstrate the trapping of single ^{85}Rb atoms in the evanescent field of a bottle-microresonator using a standing wave optical dipole trap which is created by retroreflecting a tightly focused beam on the resonator surface [4]. Atoms confined in such trapping fields will experience a spatially varying ac-Stark shift that can exceed the resonator linewidth considerably. To remove this position-dependent shift of the transition frequency of the trapped atom, we implement a dual-colour magic-wavelength trapping technique. This allows one to tune the atomic transition back into resonance with the WGM resonator.

[1] C. Junge et al. Phys. Rev. Lett. 110, 213604 (2013)
[2] M. Scheucher et al. Science 354, 1577 (2016)
[3] O. Bechler et al. Nat. Phys. 14, 996 (2018)
[4] J. D. Thompson et al. Science 340, 1202 (2013)

Q 22.27 Tue 16:30 Empore Lichthof

Towards virtual-state superradiant lasing from cold ytterbium atoms — •Dmitriy Sholokhov, Hannes Gothe, Anna Breunig, and Jürgen Eschner — Universität des Saarlandes, Campus E2 6, 66123 Saarbrücken, Germany

We analyze atom-cavity interaction and lasing from cold Ytterbium-174 atoms that are magneto-optically trapped inside a high-finesse cavity. Lasing from a 399-nm ($^1S_0-^1P_1$) MOT was previously characterized for its power, frequency and polarization properties [1]. Here, we study a possibility of implementing a similar lasing process in a superradiant, or "bad-cavity", regime by employing narrower atomic transitions. We transport the atoms from blue ($^1S_0-^1P_1$) to green ($^1S_0-^3P_1$) MOT and characterize the associated dynamics of trapped atoms and spectral properties of the light emitted by the cavity under various conditions.

[1] H. Gothe, D. Sholokhov, A. Breunig, M. Steinel, J. Eschner, Phys. Rev. A 99, 013415 (2019)

Q 22.28 Tue 16:30 Empore Lichthof

Ultra-sensitive hyperspectral imaging with a high-speed scanning microcavity — •Evgenij Vasilenko[1], Thomas Hümmer[2], Theodor Wolfgang Hänsch[2], Alexander Högele[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe — [2]Ludwig-Maximilians-Universität, München

Tunable open-access Fabry-Perot microcavities [1] enable the combination of cavity enhanced spectroscopy with high resolution imaging [2,3]. Here we describe a custom-developed scanning microcavity that enables measurements of low absorption and scattering signals at the ppm level at high rates. We analyze the stability, speed, achievable sensitivity and background limitations of the system. As an example system, we investigate individual single-walled carbon nanotubes and demonstrate quantitative extinction spectroscopy of exciton resonances, revealing the heterogeneity of E11 transitions.

[1] D. Hunger et al., New J. Phys. 12, 065038 (2010)
[2] M. Mader et al., Nature Commun. 6, 7249 (2015)
[3] T. Hümmer et al., Nature Commun. 7, 12155 (2016)

Q 22.29 Tue 16:30 Empore Lichthof

Cumulant expansion method applied to a cascaded system —

•Kasper Kusmierek, Sahand Mahmoodian, and Klemens Hammerer — Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover

Many particle systems are in general not exactly solvable, therefore the need for approximation methods arises. This work deals with such a method, called the cumulant expansion method, and its application to a cascaded system.

Q 22.30 Tue 16:30 Empore Lichthof

Climbing the Dark State Ladder of Cavity EIT — •Bo Wang[1], Christopher Ianzano[1], Nicolas Tolazzi[1], Celso Villas-Boas[2], and Gerhard Rempe[1] — [1]Max Planck Institute for Quantum Optics — [2]Universidade Federal de Sao Carlo

Dark states in atomic physics are a well-known phenomenon where normally resonant transitions are rendered *dark.* One of the most common examples of this is in a lambda-type electromagnetically induced transparency system, where laser fields drive two transitions with the same excited state. The transition amplitudes interfere destructively, preventing excitation and forming a superposition of ground states. This dark state is fragile, and is typically destroyed by additional resonant fields. Adding a strongly-coupled cavity makes the dark state more robust to perturbations and generates an infinite harmonic ladder of dark states separated by one cavity photon. A coupling field between the ground states of the lambda system accesses higher rungs of the dark state ladder by driving transitions between dark states while generating photons as the system climbs and decays from states in the ladder. Because higher lying photon number states experience both a weaker driving and an increased decay, for weak driving the system cannot surpass the one-photon dark state. An increase in the driving strength will lift this blockade and higher states will become more accessible. We demonstrate the existence of this dark-state ladder, which can be seen by a change in photon statistics between the weak- and strong-driving regimes, as well as a significantly lower population in the excited state compared to a free space atom.

Q 22.31 Tue 16:30 Empore Lichthof

A cryogenic surface-electrode ion trap apparatus for high-fidelity microwave quantum simulations — •Sebastian Halama[1], Timko Dubielzig[1], Giorgio Zarantonello[2,1], Henning Hahn[2,1], Amado Bautista-Salvador[2], 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

We report on the latest results achieved in our cryogenic surface-electrode ion trap with integrated microwave conductors for near-field quantum control of $^9Be^+$. These traps are promising systems for analog quantum simulators and for quantum logic applications. Our group developed a trap with an integrated meander-like microwave guide for driving motional sidebands on a $^9Be^+$ ion. In a room temperature apparatus, we have shown, that this kind of trap is capable of supporting entangling two-qubit gates with a fidelity of over 99 % [1]. To improve this result even further our trap operates in a cryogenic vacuum chamber. This will suppress electrical field noise, acting on the ion and originating from thermal effects [2], which could finally lead to fault tolerant quantum computation in a ion-trap based scalable architecture. We will discuss the vibration isolated closed cycle cryostat and the design of the vacuum chamber with all electrical supplies necessary to operate the trap.

[1] arXiv:1911.03954 [quant-ph] (2019)
[2] Phys. Rev. A **89**, 012318 (2014)

Q 22.32 Tue 16:30 Empore Lichthof

Optimal control for cat state preparation — •Matthias G. Krauss[1], Sabrina Patsch[1,2], Daniel M. Reich[1,2], and Christiane P. Koch[1,2] — [1]Universität Kassel, Theo. Physik III, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Freie Universität Berlin, Theo. Physik, Arnimallee 14, 14195 Berlin, 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, 441445 (2016)]. In general, the preparation of specific cat states is considered to be a hard problem in terms of numerical effort [Kallush *et al.*, New J. Phys. 16, 015008 (2014)]. Since many applications do not rely on a particular cat state, it can be beneficial to optimize towards an arbitrary n-fold cat state instead. In particular, we are interested in two types of cat states, a superposition of two coherent states in a harmonic oscillator and a superposition of two spin-coherent states in a spin system. We propose functionals for either system, which provide more freedom to the optimization algorithms, in comparison to state-to-state functionals. To analyze the practical performance of these functionals, we exemplify their use in conjunction with Krotov's method [Reich *et al.*, J. Chem. Phys. 136, 104103 (2012)].

Q 22.33 Tue 16:30 Empore Lichthof

Numerical Studies of the Quantum Game of Life — •Peter-Maximilian Ney[1], Giovanna Morigi[1], and Simone Montangero[2] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Dipartimento di Fisica e Astronomia "G.Galilei", Università di Padova, 35131 Padova, Italy

We numerically analyze the dynamics of a quantum model of the one dimensional game of life introduced in Ref. [1]. We draw analogies and differences with the classical reversible version. The simulation is done both using exact Runge-Kutta methods and matrix product state methods. Furthermore, we will concentrate on entanglement and quantum correlation structures generated by the dynamics.

[1] D. Bleh, et al., EPL 97, 20012 (2012).

Q 22.34 Tue 16:30 Empore Lichthof

Nonlocal potential of quantum measurements — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institut für TheoretischePhysik III, Heinrich-Heine-Universität Düsseldorf, D-40225Düsseldorf, Germany

The usefulness of different quantum states has been analyzed in-depth with respect to Bell nonlocality ever since the foundation of quantum information theory. Various methods to quantify the nonlocality of given quantum states have been proposed and studied in the past. However, analogous analysis with focus on the measurement side are less prevalent. We analyze the potential of given measurement operators in the context of Bell nonlocality. Specifically, we attempt to quantify how useful specific sets of quantum measurements are in terms of Bell violation, trace distance to the local polytope, the volume of nonlocality, and robustness.

Q 22.35 Tue 16:30 Empore Lichthof

Sections of generalized probabilistic theories — •Jonathan Steinberg and Matthias Kleinmann — University of Siegen, Germany

Generalized probabilistic theories (GPTs) allow us to write quantum theory in a purely operational language and enable us to formulate other, vastly different theories. Sections of GPTs can serve as a description of subsystems [1] and in general provide relations between GPTs. We investigate the structure and properties of sections of GPTs and give a complete characterization of low dimensional sections of arbitrary quantum systems. As an application we study Spekkens toy model [2] as a section. In addition, we combine the notion of sections with the dynamics in a GPT and consider the implications for quantum theory.

[1] M. Kleinmann et al., Phys. Rev. Lett. **110**, 040403 (2013)
[2] R. Spekkens, Phys. Rev. A **75**, 032110 (2007)

Q 22.36 Tue 16:30 Empore Lichthof

Lie-algebra-based estimation of the quantum speed limit — •Fernando Gago Encinas[1], Christiane Koch[1], and Thomas Chambrion[2] — [1]Institute of Theoretical Physics, Freie Universität Berlin, 14195 Berlin, Germany — [2]Institut de Mathématiques de Bourgogne, Université de Bourgogne, 21000 Dijon, France

In this work we study the needed time for a set of initial states to evolve into other target states using some of the tools typical of controllability theory. We are able to do so by using the concept of available speed $S(v) = \exp(-vB)A\exp(vB)$ which is defined for a system with a Hamiltonian $H = A + uB$ and an integral $v = \int u\,dt$ over the control. It is possible then to compute the convex hull defined by the available speed in every possible direction of the Lie algebra. Finally an optimisation algorithm is later used to tell which direction is best for reaching our goal, thus obtaining a measurement for the expected time.

Q 22.37 Tue 16:30 Empore Lichthof

Fundamental Bounds for Qubit Reset — Daniel Basilewitsch[1], •Jonas Fischer[1,2,3], Daniel M. Reich[1,3], Dominique Sugny[2], and Christiane P. Koch[1,3] — [1]Theo. Physik, Universität Kassel, D-34132 Kassel, Germany — [2]Lab. ICB, Université de Bourgogne-Franche Comté, F-21078 Dijon Cedex, France — [3]Freie Universität Berlin, Theo. Physik, Arnimallee 14, 14195 Berlin, Germany

One of the most fundamental tasks in the field of quantum technology is the purification or reset of a qubit. This process is interesting from a theoretical point of view because it raises the question of how fast entropy can be exported from a system, as well as for applications like quantum computing or quantum cryptography.

We consider a controllable qubit in contact with an environment. The environment can be mapped onto a representative pseudo-mode, decaying into a weakly coupled heat bath [D. Basilewitsch *et al*, New J. Phys. **19**, 113042 (2017)], which does not play a role for the speed limit and can be neglected. Because qubit and ancilla can be flexibly engineered, we investigate which sort of coupling and control is optimal for the reset task and search for a global speed limit.

Using the Cartan decomposition we can deduce necessary conditions for the interaction and control. We give the optimal choice for the control field depending on the coupling and also determine the overall speed limit.

Q 22.38 Tue 16:30 Empore Lichthof

Dissipative Ising model simulations with trapped ions in surface-electrode microtraps. — •Nicolás Pulido[1,2], Giorgio Zarantonello[1,2], Tim Pistorius[3], Jonathan Morgner[1,2], Amado Bautista-Salvador[2,1], Henning Hahn[1,2], Hendrik Weimer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover

Quantum simulations are the first possible applications for simple quantum information processing devices and trapped ions are a promising platform to achieve this goal. In this poster we will present a scheme for simulating the dynamics of a dissipative Ising model [1] using our current setup. The implementation will use an approach based on microwave near fields [2] and employ microwave conductors embedded in our surface-electrode trap.

[1] V. Overbeck *et al.*, Phys. Rev. A **95**, 042133 (2017)
[2] C. Ospelkaus *et al.*, PRL **101**, 090502 (2008)

Q 22.39 Tue 16:30 Empore Lichthof

Analysis of restricted Boltzmann machine quantum states — •Sebastian Syrkowski and Martin Gärttner — Kirchhoff-Institut für Physik, Heidelberg, Deutschland

For simulations of quantum many-body systems such as the transverse-field Ising model a major challenge one has to face is the exponentially growing complexity of the wave function with the number of particles prohibiting a simulation of larger systems on classical computers. Generative neural networks in the form of restricted Boltzmann machines (RBMs) have been shown to be able to represent such a quantum state more efficiently. In order to better understand the limits of this representation with respect to the complex optimization problems of ground state search and time evolution we are analyzing the topological structure of the underlying manifold of the RBM weight parameters using dimensionality reduction techniques. This allows us to test different optimization algorithms for their susceptibility to local minima.

Q 22.40 Tue 16:30 Empore Lichthof

On the notions of bound entanglement — •Michael Gaida and Matthias Kleinmann — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

The notion of bound entanglement has been widely used since the seminal work of Horodecki [Phys. Rev. Lett. 80, 5239]. However, rigorous definitions of distillability are sparse and they are not necessarily based on operational principles like LOCC. We revisit this problem and consider different definitions of distillability and the relation among them. We recover how most of those definitions are equivalent or compatible with the central theorem regarding bound entanglement.

Q 22.41 Tue 16:30 Empore Lichthof

Simulation der Zweiphotoneninterferenz am Strahlteiler — •Martin Kernbach[1], Oliver Benson[1] und Andreas Schell[2,3] — [1]Institut für Physik, AG Nano-Optik, Humboldt-Universität zu Berlin, Newtonstraße 15, Germany — [2]Institut für Festkorperphysik, Leibniz Universitat Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Zeitaufgelöste Hong-Ou-Mandel Interferenz von parallel polarisierten frequenzverstimmten Singlemodephotonen sowie Multimodephotonen.

Q 22.42 Tue 16:30 Empore Lichthof

Entanglement Generation Using Multiport Beam Splitters — •Shreya Kumar, Nico Sieber, Matthias Bayerbach, and Stefanie Barz — Universität Stuttgart, Stuttgart, Germany

Multiphoton entanglement is an integral part of optical quantum technologies. Entanglement between two photons can be either generated in sources directly or through interference of single photons at beam splitters and post-selection. We present a scheme to generate multiphoton entanglement through a balanced multiport fiber beam splitter (tritter). The balanced tritter erases the which-path information, resulting in interference, which leads to entanglement; tuning the input to the device lead to different entanglement classes. We demonstrate the scheme using three photons and generate cluster states and W-states.

Q 22.43 Tue 16:30 Empore Lichthof

Trapping, sympathetic cooling and focusing of single cerium ions for deterministic nanoresolved implantation — •Luis Ortiz-Gutiérrez, Karin Groot-Berning, Felix Stopp, Henri Lehec, and Ferdinand Schmidt-Kaler — Johannes Gutenberg-Universität Mainz

Single spins in a solid state matrix are of particular interest as a physical platform for quantum computation and quantum communication, due to its unique scalability features. Implantation of single ions in a crystal is a deterministic and precise way to realize this goal[1]. From an external ion source, doping $^{140}Ce^+$ ions are captured in a Paul trap and sympathetically cooled. The Paul trap allows a wide range of storage and cooling between light ions such as N_2^+ up to a mass of $^{232}Th^+$[2]. We extract the cerium ions and focus them to nm regime for implantation into a YAG crystal. This doped crystal has the capability of being carefully characterized by superresolution microscopy techniques as STED, in close collaboration with our partners at Univ. Stuttgart [2,3]. In addition to YAG, ions can be implanted in TiO_2, an also interesting candidate as host crystal which has a low natural abundance of nuclear spins[4]. In a new design, we aim to further improve spatial precision and the rate of implantation with different dopant ions, as well as the possibility of retrapping the extracted ions.

[1] Jacob *et al.*, Phys. Rev. Lett. 117, 043001 (2016)
[2] Groot-Berning *et al.*, Phys. Rev. Lett. 123, 106802 (2019)
[3] Kolesov *et al.*, Phys. Rev. Lett. 120, 033903 (2018)
[4] Phenicie *et al.*, arXiv:1909.06304v1 (2019)

Q 22.44 Tue 16:30 Empore Lichthof

Dynamics of a single-ion heat engine: towards a sensitive bath sensor — •Bo Deng[1], Moritz Goeb[1], Erik Torrontegui[2], Amikam Levy[3,4], Samuel Dawkins[1], Kilian Singer[1], and Daqing Wang[1] — [1]Experimentalphysik I, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Instituto de Fisica Fundamental IFF-CSIC, Calle Serrano 113b, E-28006 Madrid, Spain — [3]Department of Chemistry, University of California Berkeley, Berkeley, California — [4]The Raymond and Beverly Sackler Center for Computational Molecular and Materials Science, Tel Aviv University, Tel Aviv 69978, Israel

Recently, a single-ion heat engine was demonstrated [1]. Here, we present analytical and numerical modelling of its dynamical behaviors under the driving of thermal and non-thermal baths. A convenient and sensitive method to characterize unknown heat baths is developed. To realize the measurement, a controlled bath with a known temperature is required for reference. The unknown bath to be tested and the reference bath interact with the ion periodically. The characterization of the unknown bath is extracted from the evolution of the ion's axial oscillation. The sensitivity of this method is analyzed and compared to traditional methods of temperature measurement. Recent experimental progress is presented.

[1] J. Rossnagel, S. T. Dawkins, K. N. Tolazzi, O. Abah, E. Lutz, F. Schmidt-Kaler and K. Singer, Science 352 325 (2016).

Q 22.45 Tue 16:30 Empore Lichthof

Constructing U(1) gauge symmetry in electronic circuits — •Hannes Riechert[1], Erez Zohar[2], and Fred Jendrzejewski[1] — [1]Heidelberg University, Germany — [2]Hebrew University of Jerusalem, Israel

Classical electronic circuits have proven powerful to study several topological lattice structures (Ningyuan et al., PRX 5, 2015; Imhof et al., Nat. Phys. 14, 2019). Here, we study electronic circuits that may be described by a lattice Hamiltonian with local U(1) symmetry experimentally and explore the extent to which a classical physical simulator in the form of an electronic circuit might be useful as a stepping stone for lattice gauge theories like SU(2).

Q 22.46 Tue 16:30 Empore Lichthof

Regrouping invariance of lattice systems in a rational magnetic field — Tobias Geib, •Pablo Tieben, and Reinhard F. Werner — Institut für theroetische Physik, Leibniz Universität Hannover, Hannover, Deutschland

The traditional way of analyzing lattice systems in a magnetic field is to choose the fluxes for one cell to be rational. Then a suitable periodic grouping makes the system translation invariant, and therefore susceptible to the usual methods of band structure analysis. This method works for Hamiltonian (continuous time) systems as well as discrete time systems, so called quantum walks. Typical results obtained in this way are Hofstadter*s butterfly, representing the spectrum as a function of the field parameter, and the characterization of bands by Chern numbers.

A problem with this approach is that the results depend prima facie on the chosen regrouping. E.g. in two dimensions the regrouping can always be chosen along the x- or y- axis, but also other partitions into skew parallelograms can be used.

We show that under a technical assumption, namely the existence of a periodic gauge for the chosen regrouping, not only the spectrum is independent of the regrouping, but also the isomorphism class of the vector bundles over the Brillouin zone associated with the bands. In particular, the Chern numbers mentioned earlier are invariants. The technical assumption can be satisfied for some regroupings in any lattice dimension, and for all regroupings of two dimensional lattices. We conjecture the latter is true in every dimension.

Q 22.47 Tue 16:30 Empore Lichthof

Correlations in 2D strongly interacting fermionic systems — •Carl Heintze, Luca Bayha, Marvin Holten, Keerthan Subramanian, Philipp Preiss, and Selim Jochim — Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Many body quantum effects like superconductivity rely on the microscopic interactions of fermions. We prepare samples of ultra cold Li6-atoms confined to two dimensions to investigate the many body behavior in those systems by tuning the fermionic inter-particle interactions. In the non-interacting system, the spatial distribution of fermions is determined by the Pauli-exclusion principle and the fermions arrange themselves in a so called Pauli-crystal. Starting from non-interacting systems, we plan to observe the N-body correlations in a strongly interacting superfluid.

Even though the Pauli-crystal itself is theoretically well understood, the experimental control poses several difficulties concerning both detection and preparation. We plan to observe the spatial distribution of a six particle Pauli-Crystal using spin-sensitive and single particle resolved fluorescence imaging. By finding the correlations predicted for the non-interacting gas, we want to benchmark our setup to be able to proceed to correlations in strongly interacting systems. On this poster I want to present the experimental procedure and first results of our experiment.

In the future we want to address systems with higher particle numbers and investigate higher order correlations and pairing effects for increasing interactions.

Q 22.48 Tue 16:30 Empore Lichthof

An experiment to study small Fermi-Hubbard systems — Martin Schlederer, •Alexandra Mozdzen, Phillip Wieburg, Thomas Lompe, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, Hamburg, Deutschland

We report on an experiment designed to create small Hubbard systems site by site.

The apparatus contains two microscope objectives located inside the vacuum chamber featuring a numerical aperture of 0.75, enabling us to load single 40K atoms into individual optical tweezers and flexible tweezer arrays. This bottom-up approach will allow us to observe the emergence of many-body effects with increasing system size or particle number. We will discuss the current status of the project.

Q 22.49 Tue 16:30 Empore Lichthof

Disorder-induced Floquet topological insulator phases with Falicov-Kimball interaction — •Michael Pasek[1], Tao Qin[2], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität, D-60438 Frankfurt/Main, Germany — [2]Department of Physics, School of Physics and Materials Science, Anhui University, Hefei, Anhui Province 230601, People's Republic of China

We study topological properties of fermions in a two-dimensional circularly-shaken honeycomb lattice in the presence of a Falicov-Kimball-type interaction. In particular, we investigate whether the addition of on-site potential disorder can lead to disorder-induced Floquet topological insulator phases and whether such phases are robust against interaction effects. We use real-space non-equilibrium Floquet dynamical mean-field theory (DMFT) to obtain the steady-state of the periodically driven interacting system. To probe topological properties of the steady-state, we use the Laughlin charge pump setup on a cylinder threaded with flux, a technique well-adapted to interacting disordered systems. Finally, we show the effect of interactions by comparing results from the charge pump protocol with the predictions of the bulk topological invariant (Bott index) in the non-interacting limit.

Q 22.50 Tue 16:30 Empore Lichthof

Few ultracold fermions in a two-dimensional trap — •Ram-Janik Petzold, Jan Hendrik Becher, Ralf Klemt, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

A novel experimental setup is presented, which was designed to explore the emergence of many-body quantum effects of ultracold fermion gases in two dimensions starting from the few particle level. It mainly consists of a quasi-two-dimensional optical dipole trap for a system of countable few fermionic ^{6}Li atoms. The trap is created by two red-detuned laser beams interfering in their crossing region and providing a strong vertical confinement by a standing wave pattern. An additional single focused beam trap perpendicular to this light-sheet structure allows the independent control over the radial restriction of the harmonic trapping potential. Furthermore, the setup enables accurate control over the absolute number of particles in the trap as well as the inter-particle interaction strength and spin-resolved single-atom detection, which has already been demonstrated in a quasi-one-dimensional configuration.

It is expected that this experimental simulator will allow to study the onset of quantum many-body physics in two dimensions by mapping out correlations in position and momentum space.

Q 22.51 Tue 16:30 Empore Lichthof

Sound propagation and damping in a homogeneous two-dimensional Fermi gas — •Markus Bohlen[1,2,3], Lennart Sobirey[1,2], Niclas Luick[1,2], Hauke Biss[1,2], Thomas Lompe[1,2], and Henning Moritz[1,2] — [1]Institut für Laserphysik, Universität Hamburg — [2]The Hamburg Center for Ultrafast Imaging, Universität Hamburg — [3]École Normale Supérieure, Paris

Understanding transport in strongly interacting systems remains one of the major challenges in quantum many-body physics. In this context, two-dimensional systems are particularly intriguing due to their strong quantum fluctuations and their approximate scale invariance. Here, we present measurements of the sound propagation in a strongly interacting 2D Fermi gas across the 2D BEC-BCS crossover. We excite particle currents by imprinting a phase step onto homogeneous Fermi gases trapped in a box potential and measure the resulting density oscillations. We extract the speed of sound across the BEC-BCS crossover and compare the resulting dynamic measurement of the compressibility equation of state to a static measurement based on recording density profiles as well as a QMC calculation and find reasonable agreement between all three. Finally, we also measure the damping of the sound mode and find a clear minimum in the strongly interacting regime in agreement with quantum limited transport.

Q 22.52 Tue 16:30 Empore Lichthof

Correlation measurements of mesoscopic two-dimensional Fermi systems — Ralf Klemt, •Philipp Lunt, Jan Hendrik Becher, Ram-Janik Petzold, Philipp Preiss, and Selim Jochim

— Physics Institute, Heidelberg University, Germany

Understanding strongly correlated quantum matter on a fundamental level requires both access to microscopic correlations of individual constituents and macroscopic observables of the full system.

In recent years, we developed experimental methods to study global observables in macroscopic two-dimensional Fermi systems of ultracold lithium-6 atoms in the BEC-BCS crossover by phase coherence [1] and pairing energy [2] measurements. Furthermore, utilizing local observables on the single atom level, we can characterize microscopic quantum systems by their correlation and entanglement properties [3, 4].

Combining these two approaches, we study the crossover regime between microscopic and macroscopic systems which features already rich many-body physics, however with correlations measurements on the single particle level still feasible. We present first results on preparing and probing very dilute, yet strongly correlated, low entropy states of a few 100 atoms characterized by measurements on density and density correlations.

[1] P. Murthy et al. Science 365, 268-272 (2019) [2] P. Murthy, M. Neidig, R. Klemt et al. Science 359, 452-455 (2018) [3] A. Bergschneider, V. Klinkhamer et al. Phys. Rev. A 79, 063613 (2018) [4] P. Preiss et al. Phys. Rev. Lett. 122, 143602 (2019)

Q 22.53 Tue 16:30 Empore Lichthof

Floquet engineering of strongly correlated fermions in optical lattices — •Kilian Sandholzer, Joaquín Minguzzi, Anne-Sophie Walter, Konrad Viebahn, Frederik Görg, and Tilman Esslinger — ETH Zürich, Switzerland

The successful implementation of Floquet engineering in the field of cold atoms has enabled the study of Hamiltonians which would be out of reach in static systems. However, introducing strong interactions to these systems makes them susceptible to absorbing energy from the external drive which prevents the buildup of strong correlations.

We use an interaction-tunable Fermi gas in a periodically modulated hexagonal lattice to realize the driven Fermi-Hubbard model. In the static analog, for low temperatures nearest-neighbor spin correlations develop as a consequence of the interplay between particle hopping and onsite interactions. By driving the system close to the interaction energy, we can either enhance antiferromagnetic or induce ferromagnetic correlations. In the case of a two-frequency scheme, we demonstrate the implementation of an occupation-dependent gauge field. For these systems, a study of the evolution of doubly occupied sites shows that the heating due to the drive is not limiting the investigation of low-energy physics. In comparison to dynamical mean field theory we verify the validity of the experiments and theoretical calculations. Furthermore, we can show that the lifetime of spin correlations in a driven system can be made identical to the static system by applying coherent control to avoid heating into higher bands.

Q 22.54 Tue 16:30 Empore Lichthof

Pairing on the BEC side of a fermionic system — •Manuel Jäger[1], Thomas Paintner[1], Daniel Hoffmann[1], Wolfgang Limmer[1], Michele Pini[2], Pierbagio Pieri[2], Giancarlo Strinati[2], and Johannes Hecker Denschlag[1] — [1]Universität Ulm, Institut für Quantenmaterie, Deutschland — [2]University of Camerino, School of Science and Technology, Physics Division, Italy

We investigate the pair formation in a two-component fermionic system on the BEC side of unitarity. In the limit of weak interaction and low density, those "preformed pairs" can be approximately described by a bound state of two fermions of opposite spin. In the vicinity of the Feshbach resonance, however, the many-body character of the pairs becomes important. This strongly interacting many-body regime is still not fully understood.

For investigating this system experimentally, we use a spin-balanced mixture of the two lowest ^{6}Li Zeemann states and set their interaction strength by means of the Feshbach resonance at 832 G. We then measure the fraction of paired atoms at different temperatures and interaction strengths using optical spectroscopy. Our results are compared with an *ab initio* t-matrix calculation and a self-consistent thermal equilibrium model based on quantum statistics and effective mean field interaction. Our comparison reveals a separation between the molecular two-body and the many-body regime, although the measured pairing fraction is a thermodynamic quantity, rather than a dynamical one such as the pseudo-gap. In addition our results are used to further improve our statistical model.

Q 22.55 Tue 16:30 Empore Lichthof

Local Chern marker of smoothly confined Hofstadter fermions — •Urs Gebert, Bernhard Irsigler, and Walter Hofstetter — Goethe Universität, Frankfurt, Deutschland

The engineering of topological non-trivial states of matter, using cold atoms, has made great progress in the last decade. Driven by experimental successes, it has become of major interest in the cold atom community. In this work we investigate the time-reversal invariant Hofstadter model with an additional confining potential. By calculating a local spin Chern marker we find that topologically non-trivial phases can be observed in all considered trap geometries. This holds also for spin-orbit coupled fermions, where the model exhibits a quantum spin Hall regime at half filling. Using dynamical mean-field theory, we find that interactions compete against the confining potential and induce a topological phase transition depending on the filling of the system. Strong interactions furthermore yield a magnetic edge, which is localized through the interplay of the density distribution and the underlying topological band structure.

Q 22.56 Tue 16:30 Empore Lichthof

Fermi-Hubbard physics in 1d and bilayer systems — •Dominik Bourgund[1], Joannis Koepsell[1], Sarah Hirthe[1], Pimonpan Sompet[1], Jayadev Vijayan[1], Petar Bojovic[1], Guillaume Salomon[1], Christian Gross[1,2], and Immanuel Bloch[1,3] — [1]Max-Planck-Institut für Quantenoptik, München, Germany — [2]Physikalisches Institut, Eberhard Karls Universität Tübingen, Germany — [3]Ludwig-Maximilians-Universität München, Germany

Ultracold atoms have emerged as a powerful platform to realize the Fermi-Hubbard model in a fully controlled environment. Our quantum gas microscope gives access to full spin and density resolution and thus allows for the study of the interplay between spin and charge in doped antiferromagnets. In a one-dimensional system we observe the phenomenon of spin-charge separation by locally quenching an antiferromagnetic chain via the removal of an atom. A recent upgrade of our system now allows the study of the bilayer Fermi-Hubbard model which is of special interest in the context of high-Tc superconductivity. We investigate the bilayer phase diagram by probing the metal to band insulator as well as the Mott insulator to band insulator transition. We confirm the expected transition point at an interlayer coupling of four times the intralayer coupling. By making use of the full control over the lattice potential we employ topological charge pumping to achieve single-site resolution of each layer. This technique is benchmarked by spin resolving a 2d antiferromagnetic system.

Q 22.57 Tue 16:30 Empore Lichthof

Phase Coherence and Superfluidity in Ultracold 2D Fermi Gases — •Hauke Biss[1,3], Niclas Luick[1,3], Lennart Sobirey[1,3], Markus Bohlen[1,3,4], Vijay Pal Singh[2,3], Ludwig Mathey[2,3], Thomas Lompe[1,3], and Henning Moritz[1,3] — [1]Institut für Laserphysik, Universität Hamburg, Hamburg, Germany — [2]Zentrum für optische Quantentechnologien, Universität Hamburg — [3]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany — [4]Laboratoire Kastler Brossel, ENS-PSL Research University, CNRS, Sorbonne

In this contribution we present our studies of phase coherence and superfluidity in strongly interacting two-dimensional Fermi gases. We demonstrate phase coherence by realizing a Josephson junction in the BEC-BCS crossover. We measure the frequency of Josephson oscillations as a function of the phase difference across the junction and find excellent agreement with the sinusoidal current phase relation of an ideal Josephson junction. We probe superfluidity by dragging a red-detuned lattice through the system and observing the characteristic onset of dissipation above a critical velocity. We measure the critical velocity over the crossover at varying interaction strengths. In the limit of tightly bound molecules, as expected from the Landau criterion, the critical velocity approaches the speed of sound, whereas in the BCS limit, pair breaking excitations are the lowest mode of dissipation.

Q 22.58 Tue 16:30 Empore Lichthof

Thermoelectric transport properties of an ultracold Fermi gas — •Philipp Fabritius, Samuel Häusler, Martin Lebrat, Jeff Mohan, Laura Corman, and Tilman Esslinger — Department of Physics, ETH Zurich, 8093 Zurich, Switzerland

On this poster we present a comparison between the thermoelectric transport properties of a non-interacting Fermi gas and a unitary Fermi gas flowing through a quasi two-dimensional channel or a quantum point contact (QPC. In a first experiment we probe the thermoelectric effects induced by a temperature difference across the QPC by measuring the evolution of temperature and particle number in the reservoirs. The transport properties of channel and reservoir can be changed individually via a attractive gate beam and a narrowly focused, repulsive wall beam which changes the zero mode energy of the channel. These two tuning knobs allow to change the particle flow from hot-to-cold to cold-to-hot. This corresponds to tuning the effective Seebeck coefficient. In another experiment we probed the thermoelectric properties of a unitary Fermi gas close to the superfluid transition flowing through a QPC. Here we found that the Lorentz number does not agree with the value given by the Wiedemann-Frantz law which indicates non-Fermi liquid behavior, while the measured, non-zero Seebeck coefficient is not expected for a superfluid. Together this leads to a greatly enhanced thermoelectric efficiency. These results and recent experiments implementing local spin-filter open the way to study systems where not only heat- and particle transport is coupled but also spin.

Q 22.59 Tue 16:30 Empore Lichthof

Ergodicity breaking in tilted one-dimensional optical lattices — •Thomas Kohlert[1,2,3], Sebastian Scherg[1,2,3], Bharath Hebbe Madhusudhana[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstr. 4, 80799 München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

We study interacting ultracold Fermions in a tilted 1D optical lattice to investigate how non-ergodic dynamics can emerge in a system even in the absence of disorder. Using a superlattice to create an initial charge-density wave, we measure the population imbalance between even and odd sites as a local probe of localization. At short times, we observe spin-resolved and parity-projected real-space Bloch oscillations, which are used as benchmark for the experimental parameters such as tunneling rate, tilt and external harmonic confinement in the single-particle case. In the presence of interactions we observe an interaction-dependent amplitude modulation and dephasing of the Bloch oscillations. The long-time dynamics reveal a robust steady state imbalance over about 300 tunneling times, whose value depends on the interaction strength. Finally, we couple adjacent 1D systems to probe the crossover from a non-ergodic 1D to an ergodic 2D system and find a decay of the imbalance depending on the transverse coupling strength.

Q 22.60 Tue 16:30 Empore Lichthof

Local spin manipulation inside an atomic quantun point contact — •Philipp Fabritius, Martin Lebrat, Samuel Häusler, Jeff Mohan, Laura Corman, and Tilman Esslinger — Department of Physics, ETH Zurich, 8093 Zurich, Switzerland

We report on the control of spin inside a QPC using a local effective magnetic field. The versatility of cold-atom techniques allows us to precisely define a QPC using light potentials, to directly measure particle and spin currents and to tune interatomic interactions. In a first experiment performed with weakly interacting atoms, we locally lift the spin degeneracy of atoms inside the QPC using an optical tweezer tuned very close to atomic resonance which introduces a tunable effective Zeeman shift. We observe quantized, spin-polarized transport that is robust to dissipation and sensitive to interaction effects on the scale of the Fermi length. Using resonant light we measured the local loss around the quantum point contact which allowed us to reconstruct a two-dimensional density map similar to a scanning microscope. In a second experiment we investigate a unitary Fermi gas and the change of its transport properties when interacting with an effective Zeeman shift and spin-selective dissipation.

Q 22.61 Tue 16:30 Empore Lichthof

Learning quantum structures in compact localized eigenstates — •Giedrius Zlabys, Mantas Raciunas, and Egidijus Anisimovas — Institute of Theoretical Physics and Astronomy, Vilnius University, Sauletekio 3, LT-10257 Vilnius, Lithuania

Application of machine learning techniques for complex quantum systems provides new numerical tools to probe quantum phenomena. These tools can potentially outperform traditional methods due to their high tunability and efficient information encoding. The faithful representability of many-body states by artificial neural networks (ANNs) is now becoming established as an empirical fact and is supported by analytical evidence. On the other hand, the optimizability of a neural net remains an open issue: it is not a priori clear which models and features are well suited for machine learning techniques.

We apply ANNs to study the emergence of quantum structures in interacting bosonic systems on a lattice. We focus on the simplest one- and two-dimensional geometries that support dispersionless energy bands and the the formation of compact localized states spanning just a few neighboring sites. In the presence of interactions and at suitable values of the filling, these systems demonstrate a transition to a charge density wave. The goal is to explore how successful ANNs can be in learning quantum structures defined by compact localized states. We find that while being guided only by the noisy signal of Monte-Carlo estimates of the ground-state energy, ANNs are able to learn the defining features of quantum structures with the accuracy comparable or even superior to that of ground-state energy itself.

Q 22.62 Tue 16:30 Empore Lichthof

A driven-dissipative Bose-Einstein condensate in a 1-D optical lattice — •Marvin Röhrle[1], Jens Benary[1], Christian Baals[1,2], Alexandre Gil Moreno[1], Jian Jiang[1], and Herwig Ott[1] — [1]Department of Physics and OPTIMAS research center, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, 55128 Mainz, Germany

We experimentally investigate the behavior of a driven-dissipative Bose-Einstein condensate of weakly interacting ^{87}Rb atoms in a 1-D optical lattice. The dissipation is induced by the electron beam of a scanning electron microscope(SEM) setup, which allows us to observe a single site time resolved. Tunneling from the neighboring sites makes up the driving force. By changing the tunnel coupling J of the lattice, a first order quantum phase transition, from a coherent super fluid phase to an incoherent phase, can be seen. In between the two phases, both branches coexist in a bistable region and depending on the initial state the final state of the system changes. The filling of individual realizations of every experimental run shows a digital behavior. One site is prepared in either the super fluid phase or the incoherent resistive phase and can switch to the other branch within a few tunneling times. When observing the average dynamics over many experimental realizations a critical slowing down can be seen. Furthermore starting from an initially filled site, the losses induce a superfluid current which keeps the site filled. This complete extinction of a matter wave within a medium indicates Coherent Perfect Absorption(CPA).

Q 22.63 Tue 16:30 Empore Lichthof

Controllable Josephson junction for photon Bose-Einstein condensates — •Mario Vretenar, Ben Kassenberg, Shivan Bissesar, and Jan Klaers — University of Twente, Enschede, The Netherlands

Josephson junctions are the basis for many important fields, such as ultrafast electronics with magnetic flux quanta and superconducting quantum computing. The physical predictions of Josephson junctions are highly universal and can be observed in systems as diverse as coupled superconductors, atomic Bose-Einstein condensates, and others. We experimentally demonstrate tunable tunneling between two photon Bose-Einstein condensates by a targeted shaping of the potential landscape acting on the photons during the tunneling process. The investigated device realizes an optical analogue of a 0,π-Josephson junction, which can act as a building block for an ultrafast all-optical spin glass simulator. Such a simulator is expected to solve hard optimization problems orders of magnitude faster and more energy efficient than conventional supercomputers. The potential landscape in our photon Bose-Einstein condensate Josephson junctions is realized by a combination of direct laser writing for permanent mirror nanostructuring, and heating a thermosensitive polymer for runtime fine tuning of couplings.

Q 22.64 Tue 16:30 Empore Lichthof

Density-matrix renormalization group study of quench dynamics in the extended Bose-Hubbard model — •Sebastian Stumper, Junichi Okamoto, and Michael Thoss — Insitute of Physics, University of Freiburg, Freiburg, Germany

Dynamical quantum phase transitions (DQPTs), defined as kinks of the rate function of the Lohschmidt-echo after a global quench of the Hamiltonian, have attracted much interest over the past years. For a broad class of non-intreacting systems the occurrence of DQPTs is well established, if the initial and final Hamiltonian belong to topologically distinct phases (Phys. Rev. B 91, 155127 (2015)). On the other hand, this relation does not hold in interacting systems. The one-dimensional extended Bose-Hubbard model presents an example of an interacting model, which hosts a symmetry protected topological phase, the Haldane insulator phase, along with two trivial insulating phases, Mott insulator and density wave. We numerically investigate the dynamics of this model for quenches across phase boundaries by density-matrix renormalization group. We discuss the finite size scaling of the rate function, and show possible candidates for DQPTs.

Q 22.65 Tue 16:30 Empore Lichthof

Nonequilibrium density wave order in driven atom-cavity system — •Christoph Georges, Hans Kessler, Phatthamon Kongkhambut, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

Competing Phases and their driving are subject of interest in the field of light-induced phase in heavy-fermion systems [1] such as in light-induced superconductivity. However, because of their complex nature, materials like cuprates are delicate to theoretical grasp. Recent efforts lead to quantum gas experiments emulating simplified models for solid-state phenomena.
An ultracold gas of atoms inside a high-finesse optical cavity is one example of a versatile platform for exploring non-equilibrium phenomena and dynamical driven phase transitions in many-body systems [2]. We observe the formation of a new competing non-equilibrium density wave order in a resonantly driven Bose-Einstein Condensate coupled to the light field of a high finesse cavity. Without driving, the system organizes in a density wave that supports Braggscatting into the cavity and stabilizes itself. Meanwhile, when driving is applied, it suppresses this density wave, and a non-equilibrium density wave can be excited. This new density wave does not support further scattering into the cavity. We report on this new emerging phase in respect of driving parameters and its temporal evolution.
[1] Kogar et al. Nat. Phys. s41567-019-0705-3 (2019)
[2] C. Georges et al. Phys. Rev. Lett. 121, 220405 (2018)

Q 22.66 Tue 16:30 Empore Lichthof

Continuous feedback and spin-changing processes in a quantum gas coupled to a cavity — •Francesco Ferri, Fabian Finger, Katrin Kroeger, Rodrigo Rosa-Medina, Nishant Dogra, Marcin Paluch, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

We realize a driven-dissipative version of the Dicke model by coupling a Bose-Einstein condensate (BEC) to an optical cavity, and illuminating it with a transverse pump laser. Above a critical pump strength, the system undergoes a phase transition to a superradiant phase exhibiting self-ordering of the atomic density. The system's state can be accessed non-destructively by detecting the photons leaking from the cavity.

Here, we report on two recent advances in this context. First, we describe the implementation of an active feedback scheme to stabilize the mean intra-cavity photon number in the superradiant phase, by acting back on the pump strength. Feedback allows to approach the phase transition with a high degree of control and to extend the lifetime of the system close to criticality. Our results are a first step towards more complex feedback schemes leading to exotic many-body phases, such as limit cycles or Floquet time crystals.

In a second set of experiments, a double-frequency pump laser induces cavity-assisted Raman transitions between different spin and motional states of the BEC. An extended, fully tunable Dicke model is realized, where competing coherent and incoherent spin-changing processes occur. This scheme opens new avenues for investigating long-range spin interactions and novel magnetic phases.

Q 22.67 Tue 16:30 Empore Lichthof

Controlling spin-exchange collisions between individual neutral impurities and an ultracold quantum gas — •Sabrina Burgardt[1], Quentin Bouton[1], Daniel Adam[1], Jens Nettersheim[1], Daniel Mayer[1], and Artur Widera[1,2] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Kaiserslautern, Germany

Individual neutral atoms in an ultracold bath are a paradigmatic model of quantum impurity physics. The microscopic interaction mechanisms can be employed to use them as single-atom quantum probes, mapping information of their environment onto quantum mechanics states[1]. Individual impurities with resonant spin-exchange are the fundamental building block of the (Bose) Kondo effect, forming correlated states of the impurity with its environment.

We report a method to adjust the energy detuning in the spin-exchange dynamics of individual neutral Caesium atoms with total spin F=3 in an ultracold Rubidium gas with total spin F=1. Controlling the AC-Zeeman-Shift, induced by an off-resonant microwave or laser field, enables a selective tuning between inelastic endo- and exoergic spin-exchange collisions between the impurities and the bath. We show parameter regimes that allow tuning spin-exchange processes to resonance. This will furthermore enable future studies of impurity-bath interaction with tuneable dissipation.

[1] Q. Bouton et al., arxiv: 1906.00844, 2019

Q 23: Nano-Optics (Single Quantum Emitters) I

Time: Wednesday 11:00–13:00 Location: a310

Group Report Q 23.1 Wed 11:00 a310

Inverse design of light-matter interactions — •Robert Bennett, Jonas Matuszak, and Stefan Yoshi Buhmann — University of Freiburg, Germany

Optimal designs for photonic elements (beamsplitters, demultiplexers etc) are usually found through a combination of intuition, symmetry and previous experience. By contrast, in inverse design optimal geometries are algorithmically discovered, often leading to much higher performance. Such techniques are well-developed in the field of nanophotonics, but have not yet been applied to surface-dependent light-matter interactions such as Casimir-Polder forces or medium-assisted resonance energy transfer (RET). In this talk I will outline a very general approach recently developed in our group that allows us to optimise the observables associated with such phenomena, and give an explicit examples of a design able to increase the RET rate by several orders of magnitude.

Q 23.2 Wed 11:30 a310

Level set methods in inverse design of light-matter interactions — •Jonas Matuszak, Robert Bennett, and Stefan Yoshi Buhmann — University of Freiburg, Germany

Inverse design approaches are used to find the optimal structures for photonic elements based on their desired functional characteristics. Often the efficiency of geometries discovered by those algorithms goes far beyond those found by a design approach by hand. The level-set technique is an inverse design algorithm which consists of gradually changing the shape of a initial object by moving its boundaries. In this talk I will outline how this method can be used to optimise medium-assisted resonance energy transfer (RET).

Q 23.3 Wed 11:45 a310

Processing nanodiamonds carrying single SiV^- centers for their use in quantum technology applications — •Stefan Häussler[1], Lukas Hartung[1], Konstantin Fehler[1], Lukas Antoniuk[1], Liudmila Kulikova[2], Valery Davydov[2], Viatcheslav Agafonov[3], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Universität Ulm, 89081 Ulm, Germany — [2]L.F. Vereshchagin Institute for High Pressure Physics, Russian Academy of Sciences, Moscow 142190, Russia — [3]GREMAN, UMR CNRS CEA 6157, Université F. Rabelais, 37200 Tours, France

Color centers in nanodiamonds (NDs) offer one promising platform for a huge variety of quantum technology applications ranging from quantum networks to quantum sensors. In this course the negatively charged nitrogen-vacancy (NV^-) and silicon-vacancy (SiV^-) center have been extensively studied due to their outstanding spin and optical properties.
We present nanomanipulation of NDs exhibiting single SiV^- centers. In particular we demonstrate the translation and rotation of a ND with the help of an AFM cantilever and explicitly show that the optical properties are conserved. We further investigate the potential of these NDs for their integration into quantum optics and photonics de-

vices and the optical coupling of individual SiV^- centers in NDs.
[1] S. Häußler et al, Preparing single SiV^- center in nanodiamonds for external, optical coupling with access to all degrees of freedom, New Journal of Physics 21, 2019

Q 23.4 Wed 12:00 a310

Mechanically Isolated Quantum Emitters in Hexagonal Boron Nitride — •Michael Hoese[1], Prithvi Reddy[2], Andreas Dietrich[1], Michael K. Koch[1], Konstantin G. Fehler[1,4], Felix A. Breuning[1], Igor Aharonovich[3], Marcus W. Doherty[2], and Alexander Kubanek[1,4] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Laser Physics Centre, Australian National University, Canberra, ACT 0200, Australia — [3]Institute of Biomedical Materials and Devices, Faculty of Science, University of Technology Sydney, Ultimo, NSW 2007, Australia — [4]Center for Integrated Quantum Science and Technology (IQst), Ulm University, D-89081 Ulm, Germany

Single photon sources are crucial building blocks for novel hybrid quantum systems, which will allow for implementing quantum repeaters or other quantum network architectures. Quantum Emitters in hexagonal boron nitride (hBN) revealed promising characteristics such as persisting Fourier limited linewidths from cryogenic [1] up to room temperatures [2]. This observation was attributed to decoupling from 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. Our measurements contribute to a better understanding of single quantum emitters in hBN, thus paving the way for the implementation of novel hybrid quantum systems and quantum optics experiments at room temperature.

[1] A. Dietrich et al., Phys. Rev. B 98, 081414(R) (2018)
[2] A. Dietrich et al., arXiv:1903.02931 (2019)

Q 23.5 Wed 12:15 a310

Preparing SiV^- nanodiamonds towards a tailored single photon source — •Richard Waltrich[1], Elena Steiger[1], Stefan Häussler[1], Konstantin Fehler[1], Niklas Lettner[1], Liudmila Kulikova[2], Valery Davydov[2], Viatcheslav Agafonov[3], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Universität Ulm, 89081 Ulm, Germany — [2]L.F. Vereshchagin Institute for High Pressure Physics, Russian Academy of Sciences, Moscow 142190, Russia — [3]GREMAN, UMR CNRS CEA 6157, Université F. Rabelais, 37200 Tours, France

Defect centers in large band gap solid state materials such as the NV^- or the SiV^- color center in diamond have proven as a reliable source for many quantum optical experiments. With almost bulk like optical properties, using nanodiamonds (ND) as a host for SiV^- centers gives rise to flexible and scalable quantum systems. We investigate the optical properties of nanodiamonds and the influence of different preparation methods. Our work paves the way to quantum optical applications.

Q 23.6 Wed 12:30 a310

Highly enhanced photostability of single molecules in vacuum — •Randhir Kumar[1], Hsuan-Wei Liu[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University of Erlangen-Nürnberg, Erlangen, Germany

Single dye molecules present an excellent source of single photons with high brightness and flexibility of wavelengths. To protect them against photobleaching, one needs to shield them from the surrounding reactive agents, e.g. by embedding them in special thin films [1]. However, the finite thickness of such a medium also prevents the molecules from being placed in very small gaps necessary for very large plasmonic enhancements [2] and high spontaneous emission rate enhancement [3]. We, therefore, investigate the use of bare single dye molecules on a glass substrate. To prevent photobleaching under ambient conditions, we place the molecules in a home-built vacuum microscope that operates with a high numerical aperture at 1e-6 mbar pressure. We report on more than one order of magnitude enhancement in photostability in vacuum compared to the ambient conditions and present some prospects for exploiting our findings.

[1] Chu, Götzinger, Sandoghdar, Nature Photonics 11, 58 (2017). [2] Chikkaraddy et al., Nature 535, 127-130 (2016). [3] Matsuzaki et al., Sci. Rep. 7, 42307 (2017).

Q 23.7 Wed 12:45 a310

Optical Ramsey Spectroscopy on a Single Molecule — •Yijun Wang[1], Guilherme Stein[1], Vladislav Bushmakin[1], Jörg Wrachtrup[1,2], and Ilja Gerhardt[1] — [1]3. Institute of Physics, University of Stuttgart, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart, Germany

High-quality single photon emitters are an important building block in the field of quantum technologies. The organic dye molecule dibenzanthanthrene (DBATT, $C_{30}H_{16}$) is a notable single photon emitter that allows for high single photon purity, high photon flux and narrow-band emission simultaneously. In this work, we validate that the linewidth of the emission from the molecule can reach the Fourier limit under cryogenic conditions. We measure the transverse relaxation time T_2 by the Ramsey Spectroscopy, i.e. by applying two optical $\frac{\pi}{2}$ pulses with an interval τ on the molecule. Alternatively, we also get T_2 from the linewidth at low power limit. By confirming that T_2 is governed by the longitudinal relaxation time T_1, we conclude that the dephasing processes in the system are negligible and the linewidth of the emitted photon is truly Fourier limited, which makes the emitter ideal for quantum interference experiments.

Q 24: Quantum Information (Quantum Computing)

Time: Wednesday 11:00–13:00 Location: e001

Group Report Q 24.1 Wed 11:00 e001

Rydberg trapped ions, a novel platform for quantum computing, quantum simulation and sensing — •Arezoo Mokhberi[1], Jonas Vogel[1], Justas Andrijauskas[1,2], Ron Müller[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

Cold and controlled atoms and ions are currently of great interest for applications in quantum information processing, simulation and sensing. Excitation of trapped ions to their Rydberg states offers a unique opportunity for combining advantages of precisely controllable trapped-ion qubits with long-range and tunable Rydberg interactions [1,2]. As an exciting application, we proposed a method for fast entangling operations using Rydberg trapped ions which are shuttled in a Paul trap [3]. The state-dependent kick is resulted from impulsive electric pulses [4] acting on ions in Rydberg states with huge polarizability, and it gives rise to a geometric phase that is controlled using experimental parameters [3]. We also discuss our new experimental setup in Mainz which is designed for coherent manipulation of Rydeberg states of $^{40}Ca^+$ ions using a two-photon process, and present our results for Rydberg spectroscopy of S and D series.

[1] Feldker et al., *Phys. Rev. Lett.* **115**, 173001(2015)
[2] Higgins et al., *Phys. Rev. Lett.* **119**, 220501 (2017)
[3] Vogel et al., *Phys. Rev. Lett.* **123**, 153603 (2019)
[4] Walther et al., *Phys. Rev. Lett.* **109**, 080501 (2012)

Q 24.2 Wed 11:30 e001

Sub-microsecond entangling gate between trapped ions via Rydberg interaction — •Chi Zhang[1], Fabian Pokorny[1], Weibin Li[2], Gerard Higgins[1], Igor Lesanovsky[2,3], and Chi Zhang[1] — [1]Department of Physics, Stockholm University, 10691 Stockholm, Sweden — [2]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [3]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

Trapped Rydberg ions [1] are a novel approach for quantum information processing. By combining the high degree of control of trapped ions with the strong dipolar interaction of Rydberg atoms, fast entanglement gates may be realized in large ion crystals.

In our experiment, we excite trapped 88Sr+ ions to Rydberg states [2,3]. We have observed strong interaction between microwave-dressed Rydberg ions as a Rydberg blockade [4]. Recently, we have realized a controlled phase gate in a two ion crystal within only 700ns and entangled the ions with more than 70% fidelity [4]. This fast gate does not rely on ion motion, so it could also be applied in longer ion crystals. These are fundamental steps towards a trapped Rydberg ion quantum computer or simulator.

[1] M. Müller, et al., New J. Phys. 10, 093009 (2008).
[2] G. Higgins, et al., Phys. Rev. X 7, 021038 (2017).
[3] G. Higgins, et al., Phys. Rev. Lett. 119, 220501 (2017).
[4] C.Z. et al., arXiv:1908.11284 (2019).

Q 24.3 Wed 11:45 e001

Benchmarking high-fidelity mixed-species entangling gates — •Vera Schäfer, Amy Hughes, Keshav Thirumalai, David Nadlinger, Christopher Ballance, and David Lucas — Department of Physics, University of Oxford, UK

Simultaneous trapping of two different elements of ion allows the manipulation of one without corruption of the electronic state of the other. An entangling gate between two species offers the freedom to select ions with different strengths for different tasks, and to transfer information from one to the other depending on the task at hand. Such a gate is an essential element in quantum logic spectroscopy, quantum networking and quantum information processing.

$^{43}Ca^+$ and $^{88}Sr^+$ are two species well-suited for different aspects of quantum computing, and have transition frequencies only 20 THz apart. Therefore a two-qubit $\sigma_z \otimes \sigma_z$ gate may be driven on both species simultaneously using a single pair of Raman beams. I will present such a gate with fidelity 99.8(2)%, pushing mixed-species gate fidelities close to the best single-species entangling gates (99.9%). We use different methods to perform a full characterisation of this gate: with two-qubit randomised benchmarking we measure a fidelity of 99.72(6)% with sequences involving up to 75 entangling gates, or 30 interleaved entangling gates. From gate-set tomography we deduce a fidelity of 99.4(4)% for the two-qubit operations.

I will further present progress towards a mixed-species Mølmer-Sørensen gate on the same crystal, comparing the two methods.

Q 24.4 Wed 12:00 e001

Towards a Scalable Fault-Tolerant Ion-Based Quantum Processor — •Daniel Pijn, Janine Hilder, Alex Stahl, Max Orth, Alex Müller, Björn Lekitsch, Ferdinand Schmidt-Kaler, and Ulrich Poschinger — QUANTUM, Univ. Mainz, Institute of Physics, Staudingerweg 7, 55128 Mainz, Germany

We present steps towards the experimental realization of an error correction algorithm in a shuttling-based trapped-ion quantum processor. Ions are stored in a segmented linear Paul trap with one static laser interaction zone (LIZ). Addressed single- and two-qubit gate operations are performed by selectively transporting ions into the LIZ. The qubit register can be reconfigured by splitting, merging [1], and swapping [2] of ion crystals. Using this setup, we have previously prepared a four-qubit GHZ state [3], and used entangled ion pairs to measure magnetic field differences with a sensitivity of 12 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ [4]. Current work aims at implementing a topological error correction circuit [5]. We measure stabilizer operators on four data qubits using an additional ancilla and flag qubit [6]. Alongside the latest results we discuss our efforts to maintain the required degree of qubit coherence.

[1] Walther et al., Phys. Rev. Lett. 109, 080501 (2012)
[2] Kaufmann et al., Phys. Rev. A 95, 052319 (2017)
[3] Kaufmann et al., Phys. Rev. Lett. 119, 150503 (2017)
[4] Ruster et al., Phys. Rev. X 7, 031050 (2017)
[5] Bermudez et al., Phys. Rev. X 7, 041061 (2017)
[6] Bermudez et al, arXiv: 1810.09199 [quant-ph]

Q 24.5 Wed 12:15 e001

High-fidelity two-qubit gates using robust pulsed dynamical decoupling — Patrick Barthel[1], Jorge Casanova[2], •Patrick Huber[1], Theeraphot Sriarunothai[1], Martin Plenio[3], and Christof Wunderlich[1] — [1]Department Physik, Universität Siegen, 57068 Siegen, Germany — [2]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Spain — [3]Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, 89069 Ulm, Germany

Continuous or pulsed dynamical decoupling (DD) has been successfully used to extend the coherence time of qubits, for example in trapped atomic ions. A recently proposed, novel DD sequence is presented that not only extends the coherence time, but also results in a tunable two-qubit phase gate with high fidelity. Using both motional modes of a two-ion crystal, it allows for higher gate speeds than comparable single-mode gates [1]. We report on the experimental realization of a $\frac{\pi}{4}$-gate with a fringe contrast up to 99(2)%, applying this sequence on a set of two $^{171}Yb^+$ ions in a linear Paul trap using microwave driving fields. The interaction between motional and internal qubit states necessary for conditional quantum logic is provided by magnetic gradient induced coupling (MAGIC) [2]. We demonstrate the applicability of the sequence for Controlled-NOT operations and the creation of Bell states, as well as its robustness to errors in Rabi frequency, trap frequency and to ion temperature.

[1] I. Arrazola et al., Phys. Rev. A **97**, 052312 (2018)
[2] T. Sriarunothai et al., Quantum Sci. Technol. **4** (2019) 015014

Q 24.6 Wed 12:30 e001

Robust and resource efficient entangling gate with amplitude modulation of microwave near-fields — •Giorgio Zarantonello[1,2], Henning Hahn[1,2], Jonathan Morgner[1,2], Marius Schulte[3], Amado Bautista-Salvador[2,1], Reinhard Werner[3], Klemens Hammerer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover

The DiVincenzo criteria [1] define the requirements for quantum computing specifically the need for a universal set of quantum gates. This is satisfied by the ability to perform single qubit gates and a two qubit entangling gate. We implement such operations using near-field microwaves [2] in a surface-electrode ion trap using embedded microwave conductors. In this talk we will present a coherent control method based on amplitude modulation of the microwaves which has so far allowed to obtain Bell state infidelities in the 10^{-3} range [4].

[1] D. P. DiVincenzo, Fortschritte der Physik, **48**, 771-783(2000)
[2] C. Ospelkaus *et al.*, Nature **476**, 181 (2011)
[3] D.J. Wineland *et al.*, J. Res. NIST. **103**, 259-328 (1998)
[4] G. Zarantonello *et al.*, arXiv:1911.03954 [quant-ph]

Q 24.7 Wed 12:45 e001

Cryogenic surface-electrode ion trap apparatus for $^9Be^+$-ions — •Timko Dubielzig[1], Sebastian Halama[1], Giorgio Zarantonello[1,2], Henning Hahn[1,2], Amado Bautista-Salvador[2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

We recently commisioned a cryogenic surface electrode ion trap with integrated microwave conductors for near-field quantum control of $^9Be^+$. This trap has been operating since late November 2019 and we will present the first results. This system is a very promising environment for analog quantum simulators and for quantum logic applications. The trap is mounted to an ultra-low vibration interface, leading to a measured upper limit on vibrations caused by the cryocooler of 8 nm RMS. We operate the trap at a bias field of 223 G, where the transition between |F=2,mF=1> and |F=1,mF=1> is first-order field independent for long coherence times. Immediate perspectives for the experiment include the realization of a high-fidelity two-qubit gate, based on the recent advances in our room temperature setup, and 2D arrays of ion traps interacting via the remote Coulomb interaction as well as the implementation of effective magnetic interactions through integrated near-field microwave methods.

Q 25: Quantum gases (Bosons) IV

Time: Wednesday 11:00–13:00 Location: e214

Q 25.1 Wed 11:00 e214

Exciting an interaction-tuneable uniform Bose gas confined in flatland — •Julian Schmitt, Panagiotis Christodoulou, Maciej Galka, Nishant Dogra, Jay Man, and Zoran Hadzibabic — Cavendish Laboratory, University of Cambridge, UK

Dimensionality plays a crucial role in governing the nature of phase transitions in a system. The marginal case of two dimensions is especially interesting, where an interacting Bose gas exhibits superfluidity via the Berezinski-Kosterlitz-Thouless (BKT) topological phase transition mediated by the binding of vortices.

In this talk, I will present our recent experimental investigations to probe the collective excitations in a two-dimensional uniform Bose gas trapped in an optically sculpted box potential. Our system is derived from a Bose-Einstein-condensate of ^{39}K atoms with tuneable interactions due to a broad Feshbach resonance. Subsequently, the atoms are confined in a two-dimensional homogeneous optical box created using two different digital micromirror devices. By applying temporally changing spatial potentials, we force the superfluid out of equilibrium and monitor its density response. The emergent sound modes in the system are studied as a function of interaction strength and temperature. Importantly, the tuneability of the interactions allows us to explore the behaviour of the elementary excitations near the BKT phase transition under hydrodynamic conditions. Our system provides an ideal platform to study out-of-equilibrium situations with externally controlled dissipation channels, paving the way for studies of turbulent cascades in two-dimensional systems.

Q 25.2 Wed 11:15 e214

Single-atom quantum probes for ultracold gases using nonequilibrium spin dynamics — •Daniel Adam[1], Quentin Bouton[1], Sabrina Burgardt[1], Jens Nettersheim[1], Tobias Lausch[1], Daniel Mayer[1], Felix Schmidt[1], Eberhard Tiemann[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS TU Kaiserslautern, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

Quantum probes are atomic-sized devices mapping information of their environment to quantum mechanical states. By improving measurements and at the same time minimizing perturbation of the environment, they form a central asset for quantum technologies. Here, we present a realization of single-atom quantum probes for local thermometry based on the spin dynamic of individual neutral Caesium (probe) atoms in an ultracold gas (bath) of Rubidium atoms. The competition of inelastic endo- and exoergic spin-exchange processes map the temperature onto the quasi-spin population of the probe. The sensitivity of the thermometer can be adjusted via the external magnetic field changing the Zeeman energy splitting. Sensitivity can also be enhanced, if temperature information is obtained from the nonequilibrium dynamic, instead of the steady-state distribution, of the probe, maximizing the information obtained per inelastic collision and thus minimizing the perturbation of the bath. We will discuss the latest state of the experiment to include coherence of the probe for further quantum probing approaches.

Q 25.3 Wed 11:30 e214

Dynamical structure factors of dynamical quantum simulators — Maria Laura Baez[1,2], Marcel Goihl[2], Jonas Haferkamp[2], Juan Bermejo-Veja[2,3], •Marek Gluza[2], and Jens Eisert[2,4] — [1]Max Planck Institute for the physics of complex systems, Dresde, Germany — [2]Dahlem Center for Complex Quantum Systems, Berlin, Germany — [3]Institute for Theoretical and Computational Physics, Granada, Spain — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, Germany

The dynamical structure factor is one of the experimental quantities crucial in scrutinizing the validity of the microscopic description of strongly correlated systems. Despite its long-standing importance, it is exceedingly difficult in generic cases to numerically calculate it, ensuring that the necessary approximations involved yield a correct result. We discuss in what way results on the hardness of classically tracking time evolution under local Hamiltonians are precisely inherited by dynamical structure factors; and hence offer in the same way the potential computational capabilities as dynamical quantum simulators do. Furthermore, we improve upon a novel, readily available, measurement setup allowing for the determination of the dynamical structure factor in different architectures, including arrays of ultra-cold atoms, trapped ions, Rydberg atoms, and superconducting qubits. Our results suggest that quantum simulations employing near-term quantum devices allow for the observation of dynamical structure factors of correlated quantum matter in the presence of experimental imperfections, for larger system sizes than what is achievable by classical simulation.

Q 25.4 Wed 11:45 e214

Dissipation induced structural instability and chiral dynamics in a quantum Gas — •Nishant Dogra[1,2], Manuele Landini[1,3], Katrin Kroeger[1], Lorenz Hruby[1], Francesco Ferri[1], Rodrigo Rosa-Medina[1], Fabian Finger[1], Tobias Donner[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich, Switzerland — [2]Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [3]Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, 6020 Innsbruck, Austria

Dissipative and unitary processes define the evolution of a many-body system. Their interplay gives rise to dynamical phase transitions and can lead to instabilities. In this talk, I will present our recent observation of a non-stationary state of chiral nature in a synthetic many-body system with independently controllable unitary and dissipative couplings. Our experiment is based on a spinor Bose gas interacting with an optical resonator. Orthogonal quadratures of the resonator field coherently couple the Bose-Einstein condensate to two different atomic spatial modes whereas the dispersive effect of the resonator losses mediates a dissipative coupling between these modes. In a regime of dominant dissipative coupling we observe the chiral evolution and relate it to a positional instability.

[1] N. Dogra et al, arXiv:1901.05974 (2019).

Q 25.5 Wed 12:00 e214

Realizing the Deep Strong Coupling Regime of the Quantum Rabi Model with Ultracold Rubidium Atoms — •Geram Hunanyan, Johannes Koch, and Martin Weitz — Institut für Angewandte Physik Bonn

The dynamics of a two-level system interacting with a single bosonic mode is well described by the quantum Rabi model (QRM). Although a fair quantity of experiments explore the strong coupling regime of the QRM, where due to limited coupling strength the widely known Jaynes-Cummings model breaks down, researchers are just beginning to exploit the regime where the full QRM must be considered. Our experimental implementation to simulate the full QRM uses ultracold rubidium atoms in a 1D optical lattice potential, with the effective two-level quantum system being realized by different Bloch bands in the first Brillouin zone. The bosonic mode is represented by a vibrational mode of atoms oscillating in an optical dipole trapping potential. We experimentally observe the atomic dynamics in the deep strong coupling regime. The present status of experimental results will be presented.

Q 25.6 Wed 12:15 e214

Strongly interacting bosons in a synthetic magnetic field — •Julian Léonard, Robert Schittko, Sooshin Kim, Joyce Kwan, and Markus Greiner — Harvard University, Cambridge, MA, USA

The interplay between magnetic fields and interacting particles can lead to exotic phases of matter that exhibit topological order and high degrees of entanglement. Although these phases were discovered in a solid-state setting, recent innovations in systems of ultracold neutral atoms allow the synthesis of artificial magnetic fields. However, so far these experiments have mostly explored the regime of weak interactions, which precludes access to correlated many-body states.

We demonstrate the controlled generation of strongly correlated many-body states of bosons in a magnetic field. We use a bottom-up strategy based on quantum state engineering in the interacting Harper-Hofstadter model with tunable flux. Starting from a Fock state with a fixed number of particles, we perform a quantum annealing ramp that adiabatically connects the initial state with the target state. This allows us to reach quantum states of different fillings, particle numbers, and system sizes.

Q 25.7 Wed 12:30 e214

Bose Gases on Spheres and Ellipsoids — •Natália Móller[1], Ednilson Santos[2], Vanderlei Bagnato[3], and Axel Pelster[1] — [1]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Departamento de Fisica, Universidade Federal de Sao Carlos, Brazil — [3]Instituto de Fisica de Sao Carlos, Universidade de Sao Paulo, Brazil

Due to the prospect of experimentally realizing a Bose-Einstein condensate in a bubble-trap [1], we are interested in studying the behavior of a Bose gas on the surface of a curved manifold. The simplest geometric form approximately describing this type of trap is a spherical one, which has gained much attention in the literature and for which we have computed the low-lying excitation modes [2]. To this end we have performed a dimensional reduction of the 3D Gross-Pitaevskii (GP) equation, leading to an effective two-dimensional GP equation for the condensate wave function on the sphere and a separated equation determining the radial width, which have to be solved self-consistently. However, a more appropriate manifold to describe a bubble trap is an ellipsoid. For this case, the two-dimensional GP equation turns out to have an effective potential which results in a non-uniform ground state along the surface together with an angle-dependent width.

[1] N. Lundblad, R. A. Carollo, C. Lannert, M. J. Gold, X. Jiang, D. Paseltiner, N. Sergay, and D. C. Aveline, arXiv:1906.05885.

[2] N. S. Móller, F. E. A. dos Santos, V. S. Bagnato, and A. Pelster, in preparation.

Q 25.8 Wed 12:45 e214

NOON states with ultracold bosonic gases via resonance-assisted tunneling — •Guillaume Vanhaele and Peter Schlagheck — University of Liège, Liège, Belgium

NOON states are maximally entangled many-body states that represent an important resource for quantum information processing. In the context of ultracold bosonic atoms, they can in principle be created through quantum tunneling within a two-mode system in the self-trapping regime, where an initial |N,0> state undergoes a tunneling process towards |0,N> passing via the coherent superposition |N,0> + |0,N>. However, the time scales of such tunneling processes are in general prohibitively long for typical experimental configurations and parameters. In this talk, we show that a periodic driving of this two-mode system with suitably chosen amplitudes and frequencies can give rise to a significant enhancement of this tunneling rate. We specifically focus on the mechanism of resonance-assisted tunneling which is particularly suited for this purpose, and discuss to what extent microscopic NOON states with N=5 atoms can thereby be created on experimentally realistic time scales.

Q 26: Ultracold atoms, ions, and BEC IV (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: f303

Invited Talk Q 26.1 Wed 11:00 f303

Fate of the Amplitude Mode in a Trapped Supersolid — •Jens Hertkorn[1], Fabian Böttcher[1], Mingyang Guo[1], Jan-Niklas Schmidt[1], Tim Langen[1], Hans Peter Büchler[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

Bose-Einstein condensates (BECs) with strong magnetic dipolar interactions have an excitation spectrum that can feature a minimum known as roton minimum. In a certain interaction parameter range, the roton can induce an instability to the ground state leading to the formation of quantum droplets purely stabilized by quantum fluctuations. These droplets have been shown to realize a counter-intuitive phase of matter called supersolid, which combines the frictionless flow of a superfluid with the crystalline order of a solid.

We theoretically investigate the spectrum of elementary excitations of a trapped dipolar quantum gas across the BEC-supersolid phase transition. The energetically low-lying excitations and the relation between the spectrum of the BEC and the supersolid reveal the existence of distinct Higgs amplitude and Nambu-Goldstone modes that emerge from the softening roton modes at the phase transition point [1].

[1] J. Hertkorn et al., Phys. Rev. Lett. **123**, 193002 (2019)

Q 26.2 Wed 11:30 f303

The low-energy Goldstone mode in a trapped dipolar supersolid — •Mingyang Guo[1], Fabian Böttcher[1], Jens Hertkorn[1], Jan-Niklas Schmidt[1], Matthias Wenzel[1], Hans Peter Büchler[2], Tim Langen[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany — [2]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany

A supersolid is a counter-intuitive state of matter that combines the frictionless flow of a superfluid with the crystal-like periodic density modulation of a solid, simultaneously breaking the global gauge symmetry and translational symmetry. Although predicted more than 50 years ago, it is only recently that its defining properties are observed in ultracold quantum gases.

In this talk, I will focus on the realization of a supersolid state with a self-organized array of dipolar quantum droplets, where the crystallization arises owing to intrinsic interactions within the Dysprosium atoms. Besides the periodic density modulation and global phase coherence, the low-energy Goldstone mode, associated directly to the two broken symmetries, is observed. The dynamics of this mode features an out-of-phase oscillation of the crystal array and the superfluid density while keeping the center-of-mass constant. This mode exists only as a result of the phase rigidity of the state, and therefore confirms the superfluidity of the realized supersolid.

Q 26.3 Wed 11:45 f303

Strongly correlated Bose-Einstein Condensates with spin-orbit coupling of the Rashba-Dresselhaus type — •Clemens Staudinger and Robert E. Zillich — Institute for Theoretical Physics, Johannes Kepler University Linz, Austria

In a Bose-Einstein condensate (BEC) it is possible to couple two internal states (pseudospin up and down) in a way that the resulting Hamiltonian contains a coupling between the linear momentum and the pseudospin (Rashba-Dresselhaus coupling). Experimentally this has been achieved by irradiating the BEC with lasers of different frequencies. Such BECs have been treated extensively within mean-field theories [1]. Instead, we propose a new variational Hyper-Netted-Chain method, which accounts for correlations nonperturbatively, but is orders of magnitude faster than quantum Monte-Carlo simulations [2]. With our method we a able to accurately calculate properties of the ground-state of the BEC such as the pair-distribution function, the structure factor and other thermodynamic quantities such as the energy or the chemical potential.

[1] Y.-J. Lin, K. Jiménez-García and I. B. Spielman, Nature 471, 83 (2011).

[2] A. Ambrosetti, P. L. Silvestrelli, F. Toigo, L. Mitas, and F. Pederiva, Phys. Rev. B 85, 045115 (2012).

Q 26.4 Wed 12:00 f303

Probing the role of long-range coherence for superfluid dynamics by disorder quenches — •Jennifer Koch[1], Benjamin Nagler[1,2], Sian Barbosa[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

Quantum fluids exhibit a well-defined phase, which can be interferometrically measured. The direct connection of long-range coherence with superfluid transport and expansion dynamics is, however, challenging to access experimentally. I report on experimentally revealing the role of long-range coherence for superfluid flow in an interacting gas of ^{6}Li atoms, quenched into and out of optical disorder. I will discuss our investigations about the density and superfluid-expansion response of a molecular Bose-Einstein condensate after quenching. We measure the breakdown and reoccurrence of superfluid hydrodynamics. We track the response times on which the system relaxes to a new equilibrium and relate the time scales to fundamental energy scales of the system. Our results shed light onto the importance of long-range phase coherence for superfluid flow, and also suggest a possible route of studying complex phase dynamics in superfluids by imprinting disordered phases.

Q 26.5 Wed 12:15 f303

Tracking Rydberg atoms with Bose-Einstein Condensates — •Shiva Kant Tiwari and Sebastian Wüster — Indian Institute of Science Education and Research (IISER) Bhopal Bhopal Bypass Road, Bhauri Bhopal - 462066, M.P. India

We propose to track the position and velocity of mobile Rydberg excited impurity atoms through the elastic interactions of the Rydberg electron with a host condensate [1]. Tracks first occur in the condensate phase, but are then naturally converted to features in the condensate density or momentum distribution. The condensate thus acts analogously to the cloud or bubble chambers in the early days of elementary particle physics. The technique will be useful for exploring Rydberg-Rydberg scattering, rare inelastic processes involving the Rydberg impurities, coherence in Rydberg motion, and forces exerted by the condensate on the impurities [2]. Our simulations show that resolvable tracks can be generated within the immersed Rydberg lifetime and condensate heating is under control. Finally, we demonstrate the utility of this Rydberg tracking technique to study ionizing Rydberg collisions or angular momentum changing interactions with the condensate [3].

References: [1] R. Mukherjee, et al. Phys. Rev. Lett. 115, 040401 (2015). [2] G. E. Astrakharchik, et al. Phys. Rev. A 70, 013608 (2004). [3] M. Schlagmüller, et al. Phys. Rev. X 6, 031020 (2016).

Q 26.6 Wed 12:30 f303

Rotons and Maxons in a Rydberg-Dressed Bose-Einstein Condensate — •Gary McCormack[1], Rejish Nath[2], and Weibin Li[1] — [1]School of Physics and Astronomy, and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, Nottingham, UK — [2]Indian Institute of Science Education and Research, Pune, India

We investigate a three-dimensional Bose-Einstein condensate with a long-range soft-core two-body interaction. This interaction is induced by laser coupling the condensed atom to a highly excited Rydberg state off-resonantly. We show that the long-range interaction drastically alters the dispersion relation, giving rise to both roton and maxon modes. While rotons are typically responsible for density modulations throughout the system, maxons are normally unstable and hence decay quickly once excited, as predicted in dipolar condensates. We show that maxon modes in the Rydberg-dressed condensate, on the contrary, is stable in the dynamics. We provide a scheme to trigger the maxon mode through a quench, i.e. suddenly activation of the strong soft-core interaction. The emergence of the maxon is accompanied by persistent, high frequency oscillations in the quantum depletion, while rotons cause much slower oscillations. Through a self-consistent Bogoliubov approach, we identify the dependence of maxon modes on the soft-core interaction. We also reveal how the maxons will modify the dynamics of density-density correlations and number fluctuations of the condensate. Our study paves a new route to probe exotic quasiparticles in ultracold Bose gases with Rydberg-dressed long-range interactions.

Q 26.7 Wed 12:45 f303

Studies of circular Rydberg states in an ultracold atomic gas — •Christian Hölzl, Thomas Dieterle, Moritz Berngruber, Felix Engel, Robert Löw, Tilman Pfau, and Florian Meinert — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

Hybrid systems of ions immersed in ultracold atomic gases provide appealing means for studies comprising cold collisions, ultracold chemistry, or strongly interacting impurities. Recently, we have demonstrated a new approach for embedding a single ionic impurity into a Bose-Einstein condensate exploiting a highly excited Rydberg atom [1,2]. Here, the Rydberg core acts as a sub-μK cold ion while the Rydberg electron protects the ion from detrimental stray electric fields. In this context, circular Rydberg states are appealing candidates to improve on lifetimes of the impurity. We will present the status of our work to access circular Rydberg states from an ultracold Rubidium sample.

[1] K. S. Kleinbach, F. Engel, T. Dieterle, R. Löw, T. Pfau, and F. Meinert, Phys. Rev. Lett. 120, 193401 (2018)
[2] F. Engel, T. Dieterle, T. Schmid, C. Tomschitz, C. Veit, N. Zuber, R. Löw, T. Pfau, and F. Meinert, Phys. Rev. Lett. 121, 193401 (2018).

Q 27: Quantum Optics III

Time: Wednesday 11:00–13:00 Location: f342

Q 27.1 Wed 11:00 f342

Waveguide Integrated Superconducting Single-Photon Detector Array for Ultra-Fast Quantum Optics Experiments — •Martin A. Wolff[1,2], Fabian Beutel[1], Wladick Hartmann[1], Matthias Häussler[1], Helge Gehring[1], Robin Stegmüller[1], Nicolai Walter[1], Wolfram Pernice[1], and Carsten Schuck[1] — [1]Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]martin.wolff@wwu.de

Superconducting nanowire single-photon detectors (SNSPDs) have developed into a leading sensor technology for ultraviolet to mid-infrared light as they offer efficient photon-counting with high repetition rate, short timing jitter and low dark count rates [1]. The integration of these detectors with wideband transparent Si3N4 nanophotonic waveguides on silicon chips [2] enables novel functionality for quantum optics experiments through circuit configurability and superior sensing performance. Here we present progress towards realizing a massively parallelized system for ultra-fast single-photon detection. Our current chip comprises 16 SNSPDs fabricated from NbTiN thin-films on Si3N4 waveguides showing a fabrication yield of $> 90\%$. We realize efficient interfaces between the detectors on the chip and multiple optical fiber channels as low-loss and broadband out-of-plane couplers produced in 3D direct laser writing [3], therewith significantly widening the application space for waveguide-integrated SNSPDs, e.g. for high-bandwidth quantum key distribution with high system detection efficiency. [1] Nanophotonics, 7, 1725 (2018) [2] Appl. Phys. Lett., 102, 051101 (2013) [3] Opt. Lett. 44, 5089 (2019)

Q 27.2 Wed 11:15 f342

Characterization and Detector Tomography of Multi-Element Superconducting Single Photon Detectors — •Timon Schapeler[1], Johannes Tiedau[2], Christine Silberhorn[2], and Tim Bartley[1] — [1]Mesoskopische Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Integrierte Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Single photon detection is the basis of many applications in quantum optical technology. Increasingly, arrays of superconducting nanowire single-photon detectors (SNSPDs) are used, exploiting their high efficiency, low noise and fast recovery time. We demonstrate one way to characterize the photon statistics arising from four-element SNSPDs in terms of their detection efficiency. By a comparison of experimental data of a commercial four-pixel device and a theoretical model, we were able to account for the individual detection efficiencies of each pixel. Furthermore, we can use the statistics obtained for a multi-element device in response to known input states to perform detector tomography, thereby providing a fully quantum mechanical description of our measurement device.

Q 27.3 Wed 11:30 f342

Amorphous superconducting nanowire single-photon detectors integrated with nanophotonic waveguides — •Matthias Häussler[1], Mikhail Mikhailov[2], Martin A. Wolff[1], and Carsten Schuck[1] — [1]Institute of Physics and Center for Nanotechnology, University of Münster, D-48149 Münster, Germany — [2]B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, 61103 Kharkiv, Ukraine

Waveguide-integrated superconducting-nanowire single photon detectors (SNSPDs) are a highly promising detector technology to enable complex integrated quantum photonic experiments. While SNSPDs offer very attractive performance characteristics, current material systems only achieve limited fabrication yield, thus preventing large-scale implementations.

Here we show that waveguide-integrated SNSPDs can be realized from amorphous superconducting thin films, which promise highly reproducible nanowire fabrication because of their inherent insensitivity to the substrate material. We develop a multi-layer lithography process for patterning molybdenum silicide nanowires in travelling-wave geometry on silicon-nitride waveguides. The resulting detectors show a saturated on-chip detection efficiency of 73 % for 1550 nm wavelength photons at a temperature of 2.1 K. We further find a reset time below 5 ns allowing for high detection rates in the range of several hundred MHz. Our results pave the way for in-depth studies of fabrication yield and performance of amorphous SNSPDs integrated in large numbers on a wide range of photonic platforms.

Q 27.4 Wed 11:45 f342

Microwave cavity-free hole burning spectroscopy of Er^{3+}:Y_2SiO_5 at sub-Kelvin temperatures — •Nadezhda Kukharchyk[1], Anton Mladenov[1], Natalya Pankratova[2], Dmitriy Sholokhov[1], Alexey A. Kalachev[3], Sebastian Probst[4], Vladimir Manucharyan[2], and Pavel A. Bushev[1,5] — [1]Experimentalphysik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Department of Physics, Joint Quantum Institute and Center for Nanophysics and Advanced Materials, University of Maryland, College Park, MD 20742, USA — [3]RFC Kazan Scientific Center of RAS, 420029 Kazan, Russian Federation — [4]Quantronics group, SPEC, CEA, CNRS, Universite Paris-Saclay, CEA Saclay 91191 Gif-sur-Yvette Cedex, France — [5]JARA-Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, 52428 Jülich, Germany

Spectral hole burning technique is well-deployed in optical inhomogeneously broaden medium for realization of slow light and optical memory based on atomic frequency combs. First implementation of this technique into the microwave regime has been recently demonstrated with NV-centers coupled to a cavity [1]. Here, we develop this idea by applying spectral hole burning technique to Erbium spin ensemble in a cavity-free regime. We investigate Erbium-doped Y_2SiO_5 crystal coupled to a superconducting transmission line. Here, we show the influence of the magnetic field and temperature on the dynamics of the attained spectral hole and discuss processes governing it. [1] Putz, S., Angerer, A., Krimer, D. et al. Nature Photon **11**, 36-39 (2017)

Q 27.5 Wed 12:00 f342

Enhancing magnetic resonance via quantum optimal control — •Marco Rossignolo[1,2], Peter Höfer[3], Patrick Carl[3], Ressa S. Said[1], Tommaso Calarco[4], Fedor Jelezko[1], and Simone Montangero[2] — [1]Institute for Quantum Optics and Center for Integrated Quantum Science and Technology, Universität Ulm, D-89081 Ulm — [2]Dipartimento di Fisica e Astronomia, Università degli Studi di Padova, I-35131 Padova — [3]Bruker BioSpin, Silberstreifen 4, D-76287 Rheinstetten — [4]Institute for Quantum Control, Peter Grünberg Institut 8, Forschungszentrum Jülich GmbH, D-52525 Jülich

Electron Paramagnetic Resonance (EPR) is the technology that provides you the possibility to study the materials by exploring the internal structure and interactions between atoms and molecules via microwave fields. Exploiting particular pulse sequence schemes one can in principle decouple the system under investigation from the surrounding environment. Due to the inhomogeneities in the material, standard rectangular pulses could not work as expected and a clear view of the physics could be compromised. Here we show that by shaping the control time-dependent pulses via Optimal Control the intensity of the dominating signal has been increased in basic pulse sequences. Moreover, we enhanced furthermore the intallows of the signal, in a remote closed-loop optimization, that is, exploding the experiment feedback. This allows us to take into account unexpected sources of ntestedd perform calibration according to unknown properties of the physical system. The aforementioned results are tested for relevant industrial applications in collaboration with Bruker BioSpin.

Q 27.6 Wed 12:15 f342

Demonstration of Coherent Multitone Microwave Sequences for Simultaneous Control of all Electronic Ground States of the Nitrogen-Vacancy Center in Diamond — •Florian Böhm, Niko Nikolay, Sascha Neinert, Bernd Sontheimer, and Oliver Benson — Institut für Physik & IRIS Adlershof, Humboldt-Universität zu Berlin, Germany

The nitrogen-vacancy (NV) center in diamond is the most prominent defect in diamond due to its outstanding properties as a quantum light source and its manipulable electron spin which can easily be read-out optically. NV applications range from quantum information processing to high sensitivity nano-magnetometry [1].

In our work we explore the possibility of applying multitone microwave pulses, allowing a full simultaneous control of all three electronic ground states of the NV center. This here presented spin manipulation scheme opens up new measurement possibilities. For example spin echo techniques operating on a superposition state including all three ground states could be used to increase the NV center's magnetic field sensitivity.

After investigating the spin-forbidden coherent population swapping between the ms = -1 and ms = +1 states, without undergoing the spin allowed transition into the ms = 0 state via microwave Raman transitions we also assess if more complex multitone pulse sequences could be suitable for an enhanced magnetic field sensing.

[1] Awschalom, D. D., et al., Nat. Photonics 12.9 (2018): 516-527.

Q 27.7 Wed 12:30 f342

Purcell-Enhanced Emission from Individual Color Center in Diamond to Photonic Crystal Cavities — •Konstantin Fehler[1,2], Anna P. Ovvyan[3], Lukas Antoniuk[2], Niklas Lettner[2], Nico Gruhler[3], Valery A. Davydov[4], Viatcheslav N. Agafonov[5], Wolfram H.P. Pernice[3], and Alexander Kubanek[1,2] — [1]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [2]Institute for Quantum Optics, Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]L.F. Vereshchagin Institute for High Pressure Physics, Moscow 142190, Russia — [5]Universite F. Rabelais, 37200 Tours, France

Classical photonic platforms combined with quantum emitters, like the NV^- and 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 [2].

[1] Fehler, Konstantin G., et al. ACS Nano 2019, 13, 6, 6891-6898.
[2] Fehler, Konstantin G., et al. arXiv:1910.06114 (2019).

Q 27.8 Wed 12:45 f342

Stochastic coherence analysis of superluminescent diodes — •Kai Hansmann and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

Superluminescent diodes are semiconductor-based opto-electronic emitters with a wide range of experimental applications. For example so-called broad-area quantum-dot superluminescent diodes (QDSLDs) can be used as light sources for ghost imaging without the necessity of external diffusers [1]. The unique coherence properties of such diodes have already been the subject of theoretical investigations from a quantum mechanical point of view [2].

We present a stochastic approach to the investigation of the temporal coherence properties of QDSLDs. For this we model the spectral emission characteristics of such diodes as a superposition of stochastically fluctuating electric fields and use numerical simulations to perform coherence investigations. The results show that the properties of this spectrally broadband emitter with large intensity output can be investigated from a quantum mechanical and stochastic point of view equivalently.

[1] S. Hartmann et al.. A novel semiconductor-based, fully incoherent amplified spontaneous emission light source for ghost imaging. *Scientific Reports*, 7:41866, 2017.
[2] S. Hartmann et al.. Tailored quantum statistics from broadband states of light. *New Journal of Physics*, 17:043039, 2015.

Q 28: Precision Measurements and Metrology (Gravity)

Time: Wednesday 11:00–12:45 Location: f435

Q 28.1 Wed 11:00 f435

Fundamental investigation of micro-optomechanical devices for quantum measurements — •Mariia Matiushechkina[1,2,3,4], Bernd Schulte[1,2,3], Roman Kossak[1,2], and Michèle Heurs[1,2,3,4] — [1]Leibniz Universität Hannover, Institut für Gravitationsphysik — [2]Max Planck Institut für Gravitationsphysik — [3]QuantumFrontiers — [4]PhoenixD

The sensitivity of future generations of gravitational wave detectors (GWDs) is limited by quantum fluctuations. Quantum Radiation Pressure Noise (RPN) will soon limit the low-frequency sensitivity of interferometric GWDs. A proposed technique to reduce quantum RPN is called Coherent Quantum Noise Cancellation (CQNC) where a tailored quantum state of light couples to a mechanical system. A table-top realisation of the experiment helps to improve and investigate different parts of the set-up. It is essential to understand the basic principles of operation of the optomechanical devices to be able to modify and implement them properly in precise quantum measurements. Other noise sources, such as thermal noise, can mask quantum RPN. The realisation of their origin and numerical calculation of their power spectral densities will make it possible to reduce their influence on the optomechanical system. To model the system and to simulate applied forces, changes in temperature and initial conditions we use COMSOL Multiphysics software based on a Finite Element Method (FEM). We present our investigations into topology, mechanical properties, thermal and optical effects in the high-Q Si3N4 membranes for implementation in quantum noise cancellation experiments.

Q 28.2 Wed 11:15 f435

Gravitational Influence on Earth-based Laser Cavity Experiments — •Sebastian Ulbricht[1,2], Johannes Dickmann[1,2], Robert A. Müller[1,2], Stefanie Kroker[1,2], and Andrey Surzhykov[1,2] — [1]Physikalisch-Technische Bundesanstalt, Germany — [2]Technische Universität Braunschweig, Germany

Modern laser cavities with highly reflective mirrors are essential to the nowadays most accurate measurement devices, e.g. optical clocks, high resolution spectroscopy lasers and gravitational wave detectors. Due to the increasing demand for precision in these experiments, the stability of laser cavities underwent a tremendous improvement during the last decades. However, they are not operated in an isolated environment, but in the gravitational field of the Earth. Therefore, in this contribution, we consider the influence of Earth's gravity on laser stabilization cavities. We theoretically investigate the dynamics of electromagnetic waves in Rindler spacetime and give an analytical expression for Gaussian beams, propagating in a homogeneous gravitational field. This result is then used to obtain the output signal of a Fabry-Pérot cavity on Earth. According to our results, gravity causes changes in the intensity profile at the cavity output. Possible scenarios to measure this effect are discussed for three existing cavity settings.

Q 28.3 Wed 11:30 f435

A phase reference distribution system for LISA: Building the optical benches of the Three-Backlink Experiment — •Nicole Knust, Lea Bischof, Stefan Ast, Max Rohr, Daniel Penkert, Juliane von Wrangel, Katharina-Sophie Isleif, Oliver Gerberding, Karsten Danzmann, and Gerhard Heinzel — Leibniz Universität Hannover, Institute for Gravitational Physics, Max Planck Institute for Gravitational Physics, Albert Einstein Institute, Callinstr. 38, 30167 Hannover, Germany

LISA is planned to be a space-based observatory for gravitational waves. It will consist of three satellites arranged in a triangle, connected via laser links. To compensate the breathing of the angles between these links, each spacecraft contains two optical benches that can be actuated by so-called moving optical sub-assemblies. For exchanging the phase between both benches a flexible bi-directional link is necessary. The Three-Backlink Experiment is currently build to test different designs for such a phase reference distribution system. Beam tracing simulations using the C++ library IfoCAD were done for optimizing the set-up in terms of mitigation of spurious light. A fiber connection will be compared to a steered free beam and a fiber backlink, which is utilizing additional frequencies for the light exchange. To ensure stability and precise adjustments, the optical components are glued to the base plates. A pair of calibrated quadrant photo diodes is used in combination with a coordinate measurement machine to build the complex set-up. The talk will cover the construction process as well as results of the characterization of one of the benches.

Q 28.4 Wed 11:45 f435

Optical Metrology Terminal for Satellite-to-Satellite Laser Ranging — •Paul Koschmieder[1,2], Oliver Mandel[1,2], Michael Chwalla[1], Thilo Schuldt[2,3], Jasper Krauser[1], Dennis Weise[1], and Claus Braxmaier[2,3] — [1]Airbus Defense and Space GmbH, 88090 Immenstaad, Germany — [2]Universität Bremen, Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation (ZARM), 28359 Bremen, Germany — [3]Institut für Raumfahrtsysteme, Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), 28359 Bremen, Germany

Interferometric laser ranging is an enabling technology for high-precision satellite-to-satellite tracking within the context of earth observation, gravitational wave detection, or formation flying. Here we report on the design, setup and initial performance verification of a compact monostatic interferometric measurement terminal, set up in quasi-monolithic fashion. The design was driven by parameters such as orbit dynamics, inter-satellite distance and placement of the platform within a satellite deduced from earlier satellite missions and mission studies. A dedicated optical metrology test environment was set up, confirming the potential of the terminal to measure with nanometer accuracy. Furthermore, concepts for an end-to-end test of an inter-satellite optical metrology link are developed. This test will contain thermal and vacuum testing, as well as a simulation of in-orbit satellite dynamics and its effect on the link. This project received financial support from DLR and BMWi under grant number 50EE1407 and 50EE1409.

Q 28.5 Wed 12:00 f435

Development of a micro-integrated, crossed-beam optical dipole trap setup for integrated atomic quantum sensors — •Marc Christ[1,2], Anne Stiekel[1,2], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [2]Institut für Physik, Humboldt-Universität zu Berlin

Although generation, manipulation and detection of ultra-cold atomic matter has been demonstrated in prototypes operating in field and space environments, the transfer of these techniques into further miniaturized systems with less complexity remains an major technological challenge. One approach to reduce the size of a BEC-based sensor is to integrate optical systems within the vacuum system. This demands ultra-stable and ultra-high vacuum (UHV) compatible components and integration technologies with high mechanical and thermal resilience and alignment precision. To address UHV-compatibility, we set up a versatile qualification apparatus, enabling residual gas analysis and measurements of total gas rates down to estimated $5 \cdot 10^{-10}$ mbar l/s. A prototype design of an UHV-compatible, crossed beam optical dipole trap setup for Rubidium operating at 1064 nm, its application within a atom-chip based quantum sensor and our technology qualification efforts are described. In addition, our current work on a micro-integrated demonstrator setup for first tests with cold atoms is presented.
This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1648, 50WM1949 and 50RK1978.

Q 28.6 Wed 12:15 f435

Suitable optomechanical oscillators for an all optical coherent quantum noise cancellation exeriment — •Bernd Schulte[1,2], Daniel Steinmeyer[1,2], Mariia Matiushechkina[1,2,3], Margot Hensler Hennig[1,2], and Michèle Heurs[1,2,3] — [1]Max Planck Institute for Gravitational Physics and Institute for Gravitational Physics, Hannover, Germany — [2]Quantum Frontiers — [3]PhoenixD

Optomechanical detectors have reached the standard quantum limit in position and force sensing where backaction noise, caused by radiation pressure noise, starts to be the limiting factor for sensitivity. One strategy to circumvent measurement backaction, and surpass the standard quantum limit, has been suggested by M. Tsang and C. Caves [1] and is called Coherent Quantum Noise Cancellation (CQNC). This scheme can be viewed as coupling a second oscillator with an effectively negative mass (see J. Junker) to the one subject to quantum radiation pressure noise and thus realizing a quantum non-demolition measurement. After an introduction of the idea and the requirements for CQNC this talk will be focused on the oscillator susceptible to quantum radiation pressure noise. A Michelson interferometer was used for characterisation of the mechanical linewidth and resonance frequency of the oscillator. We discuss the measurement principles intended to determine mechanical and optical properties of our devices (membrane-in-the-middle vs. membrane-at-the-end setup). These setups could also be used to shift the mechanical properties via the optical spring effect to satisfy CQNC requirements. [1] M. Tsang and C. Caves, Phys. Rev. Lett. 105 ,123601, 2010.

Q 28.7 Wed 12:30 f435

Effective negative-mass oscillator for coherent quantum noise cancellation — •Jonas Junker[1,2,3], Daniel Steinmeyer[1,2,3], Dennis Wilken[1,2,3], and Michèle Heurs[1,2,3] — [1]Max Planck Institute for Gravitational Physics, and Institute for Gravitational Physics, Germany — [2]QuantumFrontiers — [3]PhoenixD

In opto-mechanical measurements, like in gravitational wave detectors, quantum radiation pressure noise is one of the fundamental limitations of low-frequency sensitivity. The concept of coherent quantum noise cancellation proposes to add an effective negative-mass oscillator to such a measurement system. Thus, the back-action effect caused by the quantum radiation pressure can ideally be evaded and the standard quantum limit is surpassed. In our all-optical setup, the negative-mass oscillator is implemented by a detuned optical cavity that is coupled via a beam splitter and a down conversion interaction to the light field. It needs to be matched in resonance frequency, damping and coupling strengths to the measurement system. We present the theoretical background of coherent quantum noise cancellation. Additionally, we show for which realistic conditions the negative-mass oscillator can reduce back-action noise introduced by a positive mass micromechanical oscillator (see contribution by Bernd Schulte). We explain the setup of our negative-mass oscillator consisting of a five-mirror cavity where both polarisation modes are coupled by a wave-plate as beam splitter interaction. A nonlinear crystal is placed in the cavity; this is a polarisation non-degenerate two-mode squeezing process. We will present the current status of the experiment and planned next steps.

Q 29: Quantum Effects (Entanglement and Decoherence)

Time: Wednesday 11:00–13:00 Location: f442

Q 29.1 Wed 11:00 f442

Simulating open quantum systems using quantum Zeno dynamics — •Sabrina Patsch[1,2], Sabrina Maniscalco[3], and Christiane P. Koch[1,2] — [1]Theoretische Physik, Universität Kassel, Germany — [2]Theoretische Physik, Freie Universität Berlin, Germany — [3]Turku Centre for Quantum Physics, University of Turku, Finland

Quantum simulation is most prominently used to study many-body systems which overtax even the most powerful computers, but quantum simulation is a useful tool to understand complex quantum systems of various types. Here, we present a quantum simulator which is apt to study the role of memory effects in the dynamics of open quantum systems [1]. Instead of investigating the influence of a given environment on a quantum system, we use measurements to induce dissipation in the first place. In the limit of a continuous or very strong measurement, the system's dynamics get confined to a subspace of selectable size – we observe quantum Zeno dynamics. Moreover, we can tune the non-Markovianity, i.e. the information backflow from the environment to the system, and engineer essentially arbitrary Markovian dynamics. Due to the simplicity of our scheme it can be implemented in many experimental platforms, one example being cavity QED [2]. Our quantum simulator opens the path to experimentally study memory effects, dissipation and their interplay in a controlled way – a matter of major importance since open quantum systems are ubiquitous and thus a crucial player in the pursuit of quantum technologies.

[1] Patsch, Maniscalco, Koch, arXiv:1906.11492 (2019)
[2] Raimond, et. al., PRA 86, 032120 (2012)

Q 29.2 Wed 11:15 f442

Excitonic Wave Function Reconstruction from Near-Field Spectra Using Machine Learning Techniques — •Fulu Zheng[1], Xing Gao[1,2], and Alexander Eisfeld[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Strasse 38, D-01187 Dresden, Germany — [2]Department of Chemistry, University of Michigan, Ann Arbor, Michigan 48109-1055, USA

A general problem in quantum mechanics is the reconstruction of eigenstate wave functions from measured data. Self-assembled molecular aggregates on dielectric surfaces are promising candidates for optoelectronic devices. Strong interactions between the transition dipoles of the molecules lead to delocalized excitonic eigenstates where an electronic excitation is coherently shared by many molecules [1]. Information about these states is vitally important to understand their optical and transport properties. Here we show that from spatially resolved near field spectra it is possible to reconstruct the underlying delocalized aggregate eigenfunctions [2, 3]. Although this high-dimensional nonlinear problem defies standard numerical or analytical approaches, we have found that it can be solved using a convolutional neural network. For both one-dimensional and two-dimensional aggregates we find that the reconstruction is robust to various types of disorder and noise.

[1] A. Eisfeld, C. Marquardt, A. Paulheim, and M. Sokolowski, Phys. Rev. Lett. 119, 097402 (2017). [2] X. Gao and A. Eisfeld, J. Phys. Chem. Lett. 9, 6003 (2018). [3] F. Zheng, X. Gao and A. Eisfeld, Phys. Rev. Lett. 123, 163202 (2019).

Q 29.3 Wed 11:30 f442

Lie algebra methods for solving the quantum evolution of lossy bosonic chains — •Lucas Teuber and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein–Str. 23-24, 18059 Rostock, Germany

We solve the quantum evolution of coupled harmonic oscillators experiencing Markovian loss by means of Lie algebraic methods. The coupled oscillators are described in a Liouville space formalism and their dynamics is given by a quantum master equation in Lindblad form. In Liouville space this master equation is generated by a Liouvillian just as the familiar Schrödinger equation is generated by a Hamiltonian. Utilising the Lie algebraic structure induced by the Liouvillian we can find its eigendecomposition which allows to formulate an analytic solution for the quantum state evolution. The analysis of the eigenvalues and eigenvectors enables us to find optimally transported states that mitigate the negative effects of the losses. Furthermore, knowledge of the algebraic structure grants insight into the construction of systems emulating effective non-Hermitian Hamiltonians.

Q 29.4 Wed 11:45 f442

Describing Resonance Energy Transfer by an Open Quantum Systems Approach — •Severin Bang[1], Robert Bennett[1], and Stefan Yoshi Buhmann[1,2] — [1]Institute of Physics, University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Resonance energy transfer is usually considered as a two particle process. Here we consider multiple donors and/or acceptors which share excitations (e.g. generalised Förster theory). In order to consider the most general initial states possible, we present a description of this process using the language of open quantum systems. This approach results in a master equation of the density matrix describing the multiple donor-acceptor system.

We combine this with a macroscopic quantum electrodynamical description allowing us to extend the usual description of resonance energy transfer to N atoms in arbitrary environments as well as arbitrary degrees of entanglement.

Q 29.5 Wed 12:00 f442

Entanglement and complexity in dissipative quantum cellular automata — •Javad Kazemi and Hendrik Weimer — Institut für Theoretische Physik, leibniz universität hannover, Hannover, Germany

We propose a quantum variant of cellular automata (CA) where dissipative quantum jumps enable irreversibility. As a first step, we extend one dimensional elementary CA to a two-rail platform with periodic time-dependent jump operators. Particularly, we focus on the elementary rule 110, which generates complex space-time patterns possibly capable of universal computation. We investigate a long-time coexistence of quantum entanglement and complexity by interpolating between rule 110 and dissipative dynamics preparing a highly entangled Rokhsar-Kivelson state. As a measure of complexity, we use an approach based on the computational compressibility of the measurement results obtained in the CA.

Q 29.6 Wed 12:15 f442

On open quantum systems in thermal non-ergodic environments — •Carlos Parra-Murillo[1], Max Bramberger[1], Claudius Hubig[2], and Ines de Vega[1] — [1]Department of Physics and Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-University Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermannstr. 1, 85748, Garching, Germany

In this work we investigate the failure of the weak coupling approximation standard in open quantum systems when non-Gaussian environments. We show that within this scenario, mainly characterized by non-decaying correlation functions, the derivation of a Lindblad equation is no longer possible, thus preventing the thermalization of the open quantum system while producing highly non-Markovian dynamics. We illustrate our statements by considering a thermal spin-boson environment, and show that non-decaying correlations are connected to a 1/f noise that extends to zero frequencies, providing a framework that agrees with experimental observation.

[1] C. A. Parra-Murillo et al, preprint arXiv:1910.10496

Q 29.7 Wed 12:30 f442

Speeding up a single ion thermal machine — •Moritz Goeb[1], Erik Torrontegui[2], Samuel Dawkins[1], and Kilian Singer[1] — [1]Experimentalphysik I, University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel, Germany — [2]Instituto de Fisica Fundamental IFF-CSIC, Calle Serrano 113b, E-28006 Madrid, Spain

We propose speeding up a single ion heat pump based on a tapered ion trap [1]. If a trapped ion is excited in an oscillatory motion axially the radial degrees of freedom are cyclically expanded and compressed such that heat can be pumped between two reservoirs coupled to the ion at the turning points of oscillation. Through the use of invariant-based inverse engineering, we can speed up the process without sacrificing the efficiency of each heat pump cycle. This additional control can be supplied with additional control electrodes or it can be encoded into the geometry of the radial trapping electrodes. We present a novel insight into how speed up can be achieved through the use of inverted harmonic potentials and verify the stability of such trapping conditions [2].

[1]J. Roßnagel, S. T. Dawkins, K. N. Tolazzi, O. Abah, E. Lutz, F. Schmidt-Kaler and K. Singer, Science 352 325 (2016). [2]E. Torrontegui, S. T. Dawkins, M. Göb and K. Singer, New J. Phys. 20, 105001 (2018).

Q 29.8 Wed 12:45 f442

Optimal Control Methods applied in Magnetic Resonance Fingerprinting — •Amanda Nicotina and Steffen Glaser — Technische Universität München

A method of parameter identification via Magnetic Resonance (MR) is called MR Fingerprinting (FP) recognition. The basic methods of fingerprint recognition are: fingerprinting recording, creation of data base and recognition process with a search algorithm. This can be applied to systems that can be mapped by unique measurable properties. For example, brain tissue identification using MRI. This system can be static or dynamic (influenced by external fields). In the latter, the elements of the data base consist of the time evolved observable under the action of some external field. Since the dictionary, formed by the data base, depends strongly on the external fields, designing them is crucial for the FP process. Therefore, optimal control techniques can be combined with standard FP process for better precision. The Optimal Fingerprinting Process (OFP) allows us to maximize the efficiency of the identification and minimize parameter error. This method will be used to verify relaxation parameters of a spin 1/2 spin particle. The goal is to apply OFP to improve the contrast. Therefore, having better recognition between different brain tissues, for example, the different relaxation values for white matter and gray matter in healthy brain and in Multiple Sclerosis (MS) patients.

Q 30: Annual General Meeting

Time: Wednesday 13:00–14:00 Location: f342

Duration: 60 min.

Q 31: Lunch talk: German Research Foundation (DFG) (joint session A/K/P/MO/MS/Q)

Time: Wednesday 13:10–13:55 Location: f303

Lunch Talk Q 31.1 Wed 13:10 f303

Funding by the German Research Foundation (DFG) – a brief overview — •Andreas Deschner — Deutsche Forschungsgemeinschaft (DFG), Kennedyallee 40, 53175 Bonn, Germany

During the last 100 years, the German Research Foundation (DFG) and its predecessors have been funding research in Germany. Today, the DFG is the central third party funding organization for basic research in Germany. It offers a broad spectrum of funding opportunities from individual grants to larger coordinated programs.

This talk will give a brief outline of the financial framework, the decision-making processes and the funding portfolio of the DFG. I will mostly focus on the different programs that offer support to early career scientists, e.g. the new Walter Benjamin for postdoctoral positions and the Emmy Noether program for junior research groups.

Q 32: Precision Measurements and Metrology (Optical Clocks)

Time: Wednesday 14:00–16:00 Location: a310

Q 32.1 Wed 14:00 a310

Prospects of frequency distribution networks to validate and reference satellite gravity prove Earth observation satellite missions — Stefan Schröder[1], •Simon Stellmer[2], and Jürgen Kusche[1] — [1]Institut für Geodäsie und Geoinformation, Universität Bonn, Nussallee 17, 53115 Bonn — [2]Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

Optical clocks have shown fractional instabilities in the range of 10^{-18} and continue to be improved in terms of precision and accurary, uptime, and transportability. Their "ticking rate" depends on the gravitational redshift, which opens the possibility to deploy such clocks for a measurement of the local gravitational potential. An ensemble of optical clocks could provide a geopotential reference system.

Here, we investigate the prospects of an optical time and frequency distribution network to provide a reference for satellite missions such as GRACE, GRACE-FO and Next-Generation Satellite Missions. The importance of such missions in the observation of mass transport related to climate change cannot be underestimated. New concepts to provide ground validation and referencing for these missions are highly desired.

Q 32.2 Wed 14:15 a310

Quintupling of a laser at telecom wavelength — •Maya Büki, David Röser, and Simon Stellmer — Physikalisches Institut, Uni-

versität Bonn, Nussallee 12, 53115 Bonn

The demand for highly accurate frequency standards has lead to the development and improvement of optical clocks. For a broad spectrum of applications, also outside of the laboratory, an improvement of already existing optical clocks is required. The $^1S_0 - {}^3P_0$ transition in zinc could form the basis of such a novel optical clock.

The advantage of zinc is that the clock transition at 309.5 nm and the intercombination line $^1S_0 - {}^3P_1$ at 307.6 nm can be derived as the fifth harmonic of a laser at telecom C-Band wavelength, which allows transfer of the clock signal via optical fibres.

We report on the development of a frequency quintupled diode laser at 1538 nm using three frequency conversion stages in nonlinear crystals.

Q 32.3 Wed 14:30 a310

Rubidium vapor-cell frequency references based on 5S to 6P transitions — •Julien Kluge[1], Klaus Döhringshoff[1,2], Conny Glaser[3], Florian Karlewski[4], Jens Grimmel[3], Manuel Kaiser[3], Andreas Günther[3], Helge Hattermann[3], József Fortágh[3], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen — [4]HighFinesse GmbH

Optical frequency standards based on spectroscopy of Rubidium vapor benefit from high component technology readiness level, allow for vapor-cell micro-integration and therefore physics package miniaturization. In this presentation, we discuss the optical properties of Rubidium beyond the D1/D2 line and show recent results of high precision absolute frequency measurements of the 6P manifold in conjunction with hyperfine structure constants evaluation. Additionally, we give an overview of two concepts we currently study for future compact frequency references onboard small satellites. One is based on direct modulation transfer spectroscopy of the $5S \to 6P$ transition using GaN based diode laser operating at 420 nm and the other on spectroscopy of the two-photon transition from $5S \to 5D$ at 778 nm.

This work is supported by the DLR with funds from the BMWi under grant number 50WM1857, 50RK1971 as well as by the DFG (SSP 1929 GiRyd and CIT) and BMBF (FKZ: 13N14903). C. Glaser would like to thank the Evangelische Studienstiftung Villigst e.V.

Q 32.4 Wed 14:45 a310

Progress towards a frequency measurement campaign for magnesium lattice clock — •Nandan Jha, Dominika Fim, Steffen Sauer, Waldemar Friesen-Piepenbrink, Klaus Zipfel, Wolfgang Ertmer, and Ernst Maria Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

The $^1S_0$ - $^3P_0$ clock transition of Mg with much lower sensitivity to black body radiation compared to Sr and Yb could be interesting for future room temperature optical clocks. In Hannover, we therefore are working on the development of a bosonic magnesium optical lattice clock. We have previously reported on using a two stage MOT to load 10^3 atoms into an optical lattice operating at the magic wavelength of 468 nm where the optical lattice potential generated inside an enhancement cavity allows us to perform spectroscopy in the Lamb Dicke regime. In 2017, we performed the first frequency measurement for the $^1S_0$ - $^3P_0$ clock transition in the 10^{-15} regime. In this contribution, we will discuss our recent spectroscopy measurements with a resolved clock transition linewidth of 7(3) Hz, which allows us to perform self-comparison measurements with a precision in the 10^{-17} regime. We have therefore been able to determine some of the systematic frequency shift contributions with an uncertainty in the 10^{-17} regime as well. We will give details on these preliminary measurements for the uncertainty budget as we progress towards our next frequency measurement campaign.

Q 32.5 Wed 15:00 a310

Exploring zinc as a possible candidate for optical clocks — •David Röser, Maya Büki, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

Recent advances in the development of optical clocks including the exploration of various atomic platforms lead to impressive fractional precision of frequency measurements.

Although many alkaline-earth like elements (group IIa & IIb) are investigated with regard to possible clock performance, zinc has never been investigated experimentally.

We report on the advantages of using zinc and present the status of our experiment probing suitable concepts of constructing a zinc clock.

Q 32.6 Wed 15:15 a310

Towards a strontium beam optical frequency reference based on the $^1S_0 \to {}^3P_1$ intercombination line on a sounding rocket — •Martin Jutisz[1], Oliver Fartmann[1], Conrad L. Zimmermann[1], Franz B. Gutsch[1], Vladimir Schkolnik[1], Frederik Böhle[2], Matthias Lezius[2], Ahmad Bawamia[3], Christoph Pyrlik[3], Achim Peters[1,3], Ronald Holzwarth[2], Andreas Wicht[3], and Markus Krutzik[1,3] — [1]Humboldt Universität zu Berlin — [2]Menlo Systems GmbH, Martinsried — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

Compact and rugged optical clocks and frequency references receive increased attention with respect to spaceborne operation as interspacecraft ranging often relies on frequency stabilized lasers and optical clocks are candidates for next-generation GNSS core equipment. In the OPUS project, we are working towards a compact sounding rocket payload consisting of a strontium beam optical frequency reference and a frequency comb. We utilize the 7.5 kHz broad $^1S_0 \to {}^3P_1$ intercombination line in ^{88}Sr for Ramsey-Bordé interferometry with a pre-stabilized 689 nm ECDL. Furthermore, we employ electron shelving detection on the 32 MHz broad $^1S_0 \to {}^1P_1$ line at 461 nm for reading out the interference fringes. We will give an overview on the system architecture, present first results of the ground testbed activities and discuss an expected error budget. 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 DLR50WM1851-53.

Q 32.7 Wed 15:30 a310

Control of mixed Coulomb crystals in a multi-ion clock — •Hartmut Nimrod Hausser, Tabea Nordmann, Jan Kiethe, Leon Schomburg, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The relative uncertainty of a few 10^{-18} of state-of-the-art single-ion optical clocks paves the way for new applications such as relativistic geodesy, resolving height differences with cm-precision [1] and for the search of physics beyond the standard model, e.g. for dark matter [2]. In order to resolve the atomic frequencies in shorter time the concept of the multi-ion clock was proposed [3]. Here we present the progress towards an $^{115}In^+$-multi-ion clock. In our approach, we trap $^{115}In^+$ and $^{172}Yb^+$ ions in a chip-based linear Paul trap forming a mixed Coulomb crystal. The In^+/Yb^+-configuration is optimized in terms of cooling time and reproducibility. We present the deterministic loading of a controlled number of In^+ and Yb^+ ions and reordering after collisions with background gas. Finally, we will discuss the estimated uncertainty of the indium multi-ion clock for our experimental setup.

This project has received funding from the European Metrology Programme for Innovation and Research (EMPIR) co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme (Project No. 17FUN07 CC4C).

[1] T.E. Mehlstäubler et al., *Rep. Prog. Phys.* **81**, 6 (2018).
[2] A. Derevianko, *Phys. Rev. A* **97**, 042506 (2015)
[3] C. Champenois et al., *Phys. Rev. A* **81**, 043410 (2010).

Q 32.8 Wed 15:45 a310

Charactarization of a segmented multi-ion trap for transportable optical clocks with low micro motion — •Hendrik Siebeneich[1], Florian Köppen[1], Pedram Yaghoubi[1], Michael Johanning[1], Christof Wunderlich[1], Malte Brinkmann[2], Alexandre Didier[2], Tanja Mehlstäubler[2], Stefan Brakhane[3], and Dieter Meschede[4] — [1]Universität Siegen — [2]Physikalisch Technische Bundesanstalt — [3]Toptica — [4]Universität Bonn

Single ion clocks can serve as one of today's best frequency standards with an accuracy of order 10^{-18} [1]. Developing a transportable optical ion clock using the $2S_{1/2}$ - $2D_{3/2}$ resonance with wavelength near 436 nm in a single $^{171}Yb^+$ ion is the goal of the *opticlock* [2] consortium. As part of this project we develop a next-generation set-up employing a linear multi-ion trap in order to reduce the measurement time necessary to reach a desired uncertainty. For a beneficial operation of a multi-ion clock, the rate of collisions with background gas has to be kept small. Also, sufficiently low micromotion has to be ensured for all ions in a linear ion crystal. With focus on these aspects, we present the status of the experimental setup, and characterize its operation.

[1] N. Huntemann et al., Phys. Rev. Lett. 116, 063001
[2] https://www.opticlock.de; *opticlock* is supported by the bmbf under grant no. 13N14385.

Q 33: Quantum Information (Concepts and Methods) IV

Time: Wednesday 14:00–16:00 Location: e001

Group Report Q 33.1 Wed 14:00 e001

Quantum simulations in a linear Paul trap and a 2D array — •Deviprasath Palani, Florian Hasse, Matthias Wittemer, Frederick Hakelberg, Philip Kiefer, Jan-Philipp Schröder, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of Freiburg

Trapped ions present a promising platform for quantum simulations [1]. In our linear Paul trap, we switch the trapping potential sufficiently fast to induce a non-adiabatic change of the ions' motional mode frequencies. Thereby, we prepare the ions in a squeezed state of motion. This process is accompanied by the formation of entanglement in the ions' motional degree of freedom and can be interpreted as an experimental analogue to the particle pair creation during cosmic inflation in the early universe [2].

In our basic triangular array of individually trapped ions with 40 μm inter-site distance, we realize the coupling between ions at different sites via their Coulomb interactions. We demonstrate its tuning in real-time and show interference of coherent states of currently large amplitudes [3]. In addition, we employ the individual control for local modulation of the trapping potential to realize Floquet-engineered coupling of adjacent sites [4].

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

Q 33.2 Wed 14:30 e001

Dynamical decoupling of anisotropic interacting spin ensembles — •Pablo Cova Fariña[1], Benjamin Merkel[1], Penghong Yu[1], Natalia Herrera Valencia[1], and Andreas Reiserer[1,2] — [1]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching bei München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, 80799 München, Germany

Rare-earth doped crystals are explored for quantum memory and quantum sensing applications because they can exhibit long coherence times of both spin and optical transitions. Among the rare earths, Erbium stands out for two reasons. First, its optical transition is at a telecom wavelength. Second, the large magnetic moment of its electronic spin, with effective g factors up to 16, renders it a possible candidate for quantum magnetometers with high sensitivity. Unfortunately, this large and anisotropic effective g factor comes at the prize of strong spin-spin interactions that often limit the achievable coherence time. In this work, we explore how to overcome this challenge in Er:YSO crystals using dynamical decoupling (DD). With a simple spin echo, we observe an increase of the coherence time by an order of magnitude. However, using standard DD sequences, such as XY-8, does not bring a much larger improvement, as the coherence in our 10 ppm doped crystal is limited by instantaneous diffusion. We therefore analyze the effect of novel DD sequences, both from an experimental and a theoretical point of view, and show that they can outperform standard DD sequences for anisotropic and strongly interacting spin ensembles.

Q 33.3 Wed 14:45 e001

Neural Network Heuristics for Adaptive Bayesian Quantum Estimation — Lukas J. Fiderer[1], Jonas Schuff[1,2], and •Daniel Braun[1] — [1]Institute for Theoretical Physics, University of Tübingen, Tübingen, Germany — [2]Department of Materials, University of Oxford, Oxford, United Kingdom

Adaptive experiment design is crucial in order to exploit the benefits of Bayesian quantum estimation. We propose and demonstrate a general method for creating fast and strong experiment design heuristics based on neural networks. Training of the neural networks relies on a combination of imitation and reinforcement learning. Based on the well-studied example of frequency estimation with a qubit which suffers from T_2 relaxation, we demonstrate that neural networks trained with reinforcement learning are tailored to the properties of the estimation problem and take into account the availability of resources such as time or the number of measurements. The simultaneous estimation of the frequency and the relaxation rate is considered as well. We find that the neural network heuristics are able to outperform well-established heuristics in all examples.

Q 33.4 Wed 15:00 e001

Spin-Sensitive Readout of Two-Dimensional Wigner Crystals in Transition-Metal Dichalcogenides — Johannes Knörzer[1,2], Martin J. A. Schuetz[3], •Géza Giedke[4,5], Richard Schmidt[1,2], Dominik S. Wild[3], Kristiaan De Greve[3], Mikhail D. Lukin[3], and J. Ignacio Cirac[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany — [3]Physics Department, Harvard University, Cambridge, MA 02318, USA — [4]Donostia International Physics Center, 20018 San Sebastián, Spain — [5]Ikerbasque Foundation for Science, 48013 Bilbao, Spain

Wigner crystals are prime candidates for the realization of regular electron lattices with minimal requirements on external control and a potential basis for quantum registers or simulators. However, technical challenges have prevented their detailed experimental investigation to date. Here, we investigate two-dimensional electron lattices based on self-assembled Wigner crystals in transition-metal dichalcogenides (TMDs), which provide favorable conditions for the formation of Wigner crystals. We show that they allow for minimally invasive, all-optical detection schemes of charge ordering and total spin. For suitably chosen incident light, we predict a strong dependence of the transmitted and reflected signals on the underlying lattice periodicity, thus revealing the charge order inherent in Wigner crystals. At the same time, the selection rules in TMDs provide direct access to the spin degree of freedom via Faraday rotation measurements. Prospects for the quantum simulation of spin-systems are discussed.

Q 33.5 Wed 15:15 e001

Simulation of topological phases and edge states via quantum walks with step-dependent coins — •Shahram Panahiyan and Stephan Fritzsche — Helmholtz-Institut Jena, Jena, Germany

We investigate simulations of topological phenomena in condense matter through two types of quantum walk (simple-step and split-step) with step-dependent coins. Here, we address two issues for simulation of topological phases and edge states via quantum walk. First, we show that quantum walk with step dependent coin simulates all types of topological phases and edge states. This also indicates the simulation of all types of topological phase transitions. Second, we show that step-dependent coins provide the step number as a controlling factor over the simulations. In fact, with tuning the step number, we can determine the occurrences of edge states/topological phases, the type of edge state/topological phases and where they should be located.

Q 33.6 Wed 15:30 e001

Topological order in perturbed toric code models — •Amit Jamadagni Gangapuram and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Hannover, Germany.

We present a few signatures to detect topological order using concepts from quantum information. Based on the toric code model, we construct various closed and open quantum systems that encode a possible topological phase transition. We compare various approaches to topological order by their ability to successfully detect topological phase transitions within these models.

Q 33.7 Wed 15:45 e001

Unsupervised phase discovery with deep anomaly detection — •Korbinian Kottmann[1], Patrick Hümbeli[1], Maciej Lewenstein[1,2], and Antonio Acin[1,2] — [1]ICFO, Avinguda Carl Friedrich Gauss, 3, 08860 Castelldefels — [2]ICREA, Passeig de Lluís Companys, 23, 08010 Barcelona

We present a novel method for automated and unsupervised discovery of new and unknown phases in quantum many-body scenarios. Instead of supervised learning, where data is classified using labeled data, we perform anomaly detection, where the task is to differentiate a normal data set, composed of one or several classes, from anomalous data. We propose a scheme, employing deep neural networks, to map out the whole phase diagram. The method can be used completely unsupervised and automated to explore the entire phase diagram. As a paradigmatic example, we explore the phase diagram of the extended Bose Hubbard model in one dimension at integer filling. We compute the ground states using tensor networks and exemplarily use both unprocessed data like the central tensor and processed data like entanglement spectra that suffice to reproduce the phase diagram. The formulation of the method is independent of the nature of the data and could as well be used with physical observables, i.e. experimental data.

Q 34: Quantum gases (Fermions) II

Time: Wednesday 14:00–16:00 Location: e214

Invited Talk Q 34.1 Wed 14:00 e214

Zooming in on Fermi Gases in Two Dimensions — •Philipp Preiss, Luca Bayha, Jan Hendrik Becher, Marvin Holten, Ralf Klemt, Philipp Lunt, Keerthan Subramanian, and Selim Jochim — Physics Institute, Heidelberg University

Interacting Fermi systems in two dimensions display interesting phenomena including strongly correlated superfluids, pseudogap physics, and collective excitations. Certain limits, such as the weakly interacting regime and the few-body case, can be modeled exactly, but for a large parameter space in particle number and interaction strength, predicting the relevant physical properties theoretically is extremely challenging.

I will report on experiments that realize tunable fermion systems with ultracold lithium and span large swaths of the interesting regime. We have assembled a complete experimental toolbox to study such systems with single-particle resolution in position and momentum space.

In the well-controlled few-body scenario, we deterministically prepare few fermions in the ground state of a two-dimensional trap and observe the formation of shell structure with stable “magic” numbers of 2,6,12 particles. Through many-body spectroscopy, we find well-defined resonances that consists of pairwise excitations and can be identified as the precursor of the Higgs amplitude mode.

Scaling the system to sizes of several hundred particles, we are able to probe strongly correlated continuum systems with the microscopic tools of particle-resolved correlation functions.

Q 34.2 Wed 14:30 e214

Direct observation of superfluidity in an ultracold two-dimensional Fermi gas — •Lennart Sobirey, Markus Bohlen, Niclas Luick, Hauke Biss, Thomas Lompe, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, Deutschland

Understanding the mechanism for superfluidity in low dimensional systems with strong correlations is one of the major unsolved problems of condensed matter physics. Ultracold two-dimensional Fermi gases model these systems in a clean and controllable way, but so far, superfluidity has not been directly observed. Here, we present direct evidence of superfluidity in a strongly interacting 2D Fermi gas. We drag an optical lattice through a homogeneous 2D Fermi gas and observe no dissipation below a critical velocity, in excellent agreement with the Landau criterion. We find evidence for superfluidity across a wide range of interaction strengths in the BEC-BCS crossover.

Q 34.3 Wed 14:45 e214

An ideal Josephson junction in an ultracold two-dimensional Fermi gas — •Niclas Luick[1,2], Lennart Sobirey[1,2], Markus Bohlen[1,2,3], Vijay Pal Singh[4,2], Ludwig Mathey[4,2], Thomas Lompe[1,2], and Henning Moritz[1,2] — [1]Institut für Laserphysik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg — [3]Laboratoire Kastler Brossel, ENS-PSL Research University, CNRS, Sorbonne Université, Collège de France, 24 rue Lhomond, 75005 Paris, France — [4]Zentrum für optische Quantentechnologien, Universität Hamburg

Two-dimensional structures are present in almost all known superconductors with high critical temperatures, but the role of the reduced dimensionality is still under debate. Recently, ultracold atoms have emerged as an ideal model system to study such strongly correlated 2D systems.

Here, we present our realisation of a Josephson junction in an ultracold 2D Fermi gas. We measure the frequency of Josephson oscillations as a function of the phase difference across the junction and find excellent agreement with the sinusoidal current phase relation of an ideal Josephson junction. Furthermore, we determine the critical current of our junction in the crossover from tightly bound molecules to weakly bound Cooper pairs. Our measurements clearly demonstrate phase coherence and provide strong evidence for superfluidity in a strongly interacting 2D Fermi gas.

Q 34.4 Wed 15:00 e214

Ergodicity-breaking in tilted 1D optical lattices — •Sebastian Scherg[1,2,3], Thomas Kohlert[1,2,3], Bharath Hebbe Madhusudhana[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstr. 4, 80799 München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

We study interacting ultracold Fermions in a tilted 1D optical lattice to investigate, how non-ergodic dynamics can emerge in a system even without the presence of disorder. Using a superlattice to create an initial charge-density wave, we measure the population imbalance between even and odd sites. At short times, we observe spin-resolved and parity-projected real-space Bloch oscillations, which are used as benchmark for the experimental parameters such as tunneling rate, tilt and harmonic confinement in the non-interacting regime. In the presence of interactions we observe an interaction-dependent amplitude modulation and dephasing of the Bloch oscillations. The long-time dynamics reveal a robust steady state imbalance over about 300 tunneling times, whose value depends on the interaction strength. Finally, we couple adjacent 1D systems to probe the crossover from a non-ergodic 1D to an ergodic 2D system and find a decay of the imbalance depending on the transverse coupling strength.

Q 34.5 Wed 15:15 e214

Correlation measurements of mesoscopic two-dimensional Fermi systems — •Ralf Klemt, Philipp Lunt, Jan Hendrik Becher, Ram-Janik Petzold, Philipp M. Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Understanding strongly correlated quantum matter on a fundamental level requires both access to microscopic correlations of individual constituents and macroscopic observables of the full system.

In recent years, we developed experimental methods to study global observables in macroscopic two-dimensional Fermi systems of ultracold ^6Li atoms in the BEC-BCS crossover by phase coherence and pairing energy measurements. Furthermore, utilizing local observables on the single atom level, we can characterize microscopic quantum systems by their correlation and entanglement properties.

Combining these two approaches, we study the crossover regime between microscopic and macroscopic systems which features already rich many-body physics, however with correlations measurements on the single particle level still feasible. In this talk, I will present first results on preparing and probing very dilute, yet strongly correlated, low entropy states of a few 100 atoms characterized by measurements on density and density correlations.

Q 34.6 Wed 15:30 e214

Strongly correlated fermions strongly coupled to light — •Hideki Konishi, Kevin Roux, Victor Helson, and Jean-Philippe Brantut — Institute of Physics, EPFL, Lausanne, Switzerland

We demonstrate strong coupling of a strongly interacting Fermi gas with light in a high finesse optical cavity. A quantum degenerate, unitary Fermi gas of lithium-6 is produced inside the cavity mode, and the transmission spectrum of the coupled system is measured. We investigate both a spin-polarized and a spin-balanced gas. In the spin-polarized case the spectrum shows a prominent anti-crossing as the cavity approaches the atomic resonance, a hallmark of strong light-matter coupling. In the spin-balanced case we observe three dressed state branches corresponding to the two internal states, in a regime where the collective Rabi frequency is larger than the hyperfine splitting. Both spectra are in good agreement with ab-initio theoretical calculations. Our system provides complete and simultaneous control over the atom-atom and atom-light interactions. It allows for the implementation of novel light-induced phases of matter as well as continuous measurements of atomic dynamics.

Q 34.7 Wed 15:45 e214

Approximate theories for an interacting wannier-stark ladder — •Bharath Hebbe Madhusudhana[1,2,3], Sebastian Scherg[1,2,3], Thomas Kohlert[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, 4 Schellingstraße, 80799 München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Max Planck Institute for Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

The Wannier-Stark ladder is a simple 1D lattice system that features localization. Its Hamiltonian consists of a nearest neighbor hopping and a linear on-site potential resulting in a tilt . In the non-interacting case, this systems is analytically tractable. However, in the presence of Hubbard interactions, due to an exponential scaling of the dimension of the Hilbert space, theoretical and numerical computations are limited to either small system sizes or short evolution times. Here, we use an analog quantum simulator made of trapped neutral atoms to experimentally study the localization dynamics of a Wannier-Stark ladder with Hubbard interactions. Using the experimental results, we develop and benchmark an approximate theoretical model for our system and show that the experimental results are well approximated by the theory. The computational complexity of this theory is at-most linear in the system size and therefore, the system dynamics can be computed efficiently using this theory. We also apply this theory to the Aubry-André model, which is another Hamiltonian that features localization, and show a good agreement with experimental data.

Q 35: Cold Molecules I (joint session MO/Q)

Time: Wednesday 14:00–15:15 Location: f102

Q 35.1 Wed 14:00 f102

Optical pumping of metastable helium: state purification and spin-state selection — •J. Guan, T. Sixt, A. Tsoukala, F. Stienkemeier, and K. Dulitz — Institute of Physics, University of Freiburg, Herman-Herder-Str.3, 79104 Freiburg, Germany

Discharge and electron-impact excitation lead to the production of metastable helium atoms in two metastable states, 2^3S_1 and 2^1S_0. However, many applications require purified beams containing only one of these species. For atom magnetometers and spin-controlled collisions, even magnetic quantum state selection is required.

Recently, we have successfully applied optical quenching via the $4^1P_1 \leftarrow 2^1S_0$ transition at 397 nm to fully deplete the 2^1S_0 population in a ^{4}He gas beam.[1] Equipped with a tunable laser at 1083 nm for excitation of $2^3S_1 \rightarrow 2^3P$ transitions, we continue to make progresses on preparing the spin-labelled 2^3S_1 state after optical quenching. In this talk, I will show our results on the optical quenching of He (2^1S_0) and on the optical pumping of He (2^3S_1). The spin-controlled metastable He atoms (2^3S_1, $m_J = 1$, 0 or -1) are an ideal source for studying cold and controlled reactive collisions and I will outline possible experiments using this setup.

Reference: 1. Guan et al., Phys. Rev. Appl. 11, 054073 (2019).

Q 35.2 Wed 14:15 f102

The diatomic molecular spectroscopy database for laser cooling and trapping — •Xiangyue Liu, Stefan Truppe, Gerard Meijer, and Jesus Perez-Rios — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany

Convenient access to the spectroscopic constants of molecules is essential for the screening of potential candidates for laser cooling and trapping techniques. To this end, we present a user-friendly database-driven website that provides the ground and excited states spectroscopy constants of polar diatomic molecules, implemented with Linux, Apache, MySQL, and PHP (LAMP) on the back end. The Franck-Condon factors, which directly determine the transition probabilities between two vibrational states, are directly calculated from the spectroscopic constants. In this website, the user can either search for the spectroscopic constants from the web page user interface or access freely to the data from the application programming interface (API). In the API, the data is given in in lightweight data-interchange formats, including JSON and CSV. The user, after registration, is also allowed to contribute to the database. We believe that this database may advance the research in molecular spectroscopy and, ultimately, in ultracold molecules.

Q 35.3 Wed 14:30 f102

Suppression of Penning ionization by orbital angular momentum conservation — •Tobias Sixt, Jiwen Guan, Jonas Grzesiak, Markus Debatin, Frank Stienkemeier, and Katrin Dulitz — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg im Breisgau, Germany

The efficient suppression of Penning-ionizing collisions is a stringent requirement to achieve quantum degeneracy in metastable rare gases. In our experiment, we study quantum-state-controlled Penning collisions between laser-cooled lithium atoms (Li) and metastable helium atoms (He*) to investigate new ways of controlling the outcome of Penning-ionizing collisions.

In this contribution, we report on the efficient suppression of He*-Li Penning ionization by laser excitation of the Li atoms. The results illustrate that not only the electron spin, but also Λ - the projection of the total molecular orbital angular momentum along the internuclear axis - is conserved during the ionization process. Our findings suggest that Λ conservation can be used as a more general means of reaction control, for example, to improve schemes for the simultaneous laser cooling and trapping of He* and alkali atoms.

Q 35.4 Wed 14:45 f102

Line shape investigation of the electronic origin of phthalocyanines, porphyrins and their clusters with H_2O I: Helium nanodroplet studies — •Johannes Fischer, Florian Schlaghaufer, and Alkwin Slenczka — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93053 Regensburg, Germany

Despite vanishing viscosity the spectral shape of the zero phonon line at the electronic origin of molecules embedded into superfluid helium nanodroplets does not reveal the band system of a free rotor. According to previous investigations, helium induced inhomogeneous line broadening dominates the experimentally observed optical line shape. To decipher pure molecular and helium induced contributions the line shapes of various organic compounds and their clusters with H_2O were recorded by means of electronic spectroscopy as well as electronic Stark spectroscopy. In order to learn about the dopant species its spectroscopic response must be separated from the helium induced spectral features. We present electronic spectra and Stark-spectra of phthalocyanine-H_2O clusters, dipolar chloroaluminiumphthalocyanine, and of chloroaluminiumphthalocyanine-H_2O clusters. Thereby we observe field induced optical anisotropy and spectral changes of the line shape. A final analysis requires in addition high-level *ab initio* calculations for the corresponding isolated species [1]. Moreover, the helium droplet work is accompanied by corresponding investigations in the gas phase, which are subject of a follow up talk (F. Schlaghaufer).

[1] J. Fischer et al., *J. Phys. Chem.*, **123**, 10057, (2019).

Q 35.5 Wed 15:00 f102

Line shape investigation of the electronic origin of phthalocyanines, porphyrins and their clusters with H_2O II: gas phase studies — •Florian Schlaghaufer, Johannes Fischer, and Alkwin Slenczka — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93053 Regensburg, Germany

The spectral shape of the zero-phonon-line in the electronic and Stark spectra of organic molecules such as phthalocyanines [1] and porphine

[2] and their clusters with small molecules (e.g. H_2O) recorded in superfluid helium nanodroplets is determined by pure molecular contributions and the influence of the helium environment. As discussed in an accompanying talk (J. Fischer), the analysis of such line shapes is not straightforward. Therefore, corresponding gas phase studies are essential for dissecting helium induced spectral features from molecular rotor fingerprints. The observed rotational band shapes of jet cooled molecules and associated simulations give insight into the structure and polarity of the molecular systems for both the ground and the electronically excited state. By means of a rule of thumb for transition from gas phase to helium droplet conditions we compare these simulations with experimental spectra measured in helium droplets. Mismatches reveal the influence of helium induced contributions to the line shapes. Ultimately, this project heads for a better understanding of microsolvation and the dynamics of electronic excitation of molecules inside superfluid helium nanodroplets.

[1] J. Chem. Phys. 2018, 148, 144301.
[2] J. Chem. Phys. 2018, 149, 244306.

Q 36: Ultracold plasmas and Rydberg systems I (joint session Q/A)

Time: Wednesday 14:00–16:00 Location: f342

Q 36.1 Wed 14:00 f342

Free-space QED with Rydberg superatoms — •Nina Stiesdal, Hannes Busche, and Sebastian Hofferberth — University of Southern Denmark, Odense, Denmark

Rydberg quantum optics (RQO) allows to create strong optical nonlinearites at the level of individual photons by mapping the strong interactions between collective Rydberg excitations onto optical photons.

The strong interactions lead to a blockade effect such that an optical medium smaller than the blockaded volume 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 few-photon probe fields with directional emission into the initial probe mode.

Here we discuss how we use Ryderg superatoms to study the dynamics of single two level systems strongly coupled to quantized propagating light fields, enabling e.g. the investigation of three-photon correlations mediated by a single quantum emitter.

We also show our experimental progress towards implementing a cascaded quantum system by interfacing multiple superatoms with a single probe mode.

Q 36.2 Wed 14:15 f342

Self-Induced Transparency in Room-Temperature Dense Rydberg Gases — •Zhengyang Bai[1,2], Weibin Li[1], and Guoxiang Huang[2] — [1]School of Physics and Astronomy, and Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, UK — [2]State Key Laboratory of Precision Spectroscopy, East China Normal University, Shanghai 200062, China

Aggressively large Doppler effects is of the challenge to create static optical nonlinearities in atomic gases beyond ultracold temperatures. We show the creation of strong dispersive optical nonlinearities of nanosecond laser pulses in high number density atomic gases at room temperature. This is examined in a vapor cell setting where the laser light resonantly excites atoms to Rydberg P states through a single-photon transition. Using fast Rabi flopping and strong Rydberg atom interactions, both in the order of GHz, can overcome the Doppler effect as well as dephasing due to thermal collisions between Rydberg electrons and surrounding atoms. In this strong-driving regime both the light intensity and Rydberg interactions contribute to the generation of the optical nonlinearity. We show the emergence of a modified self-induced transparency (SIT) where the stable light propagation relies on the Rydberg interactions. We identify quantitatively that the SIT occurs at smaller (than 2π) pulse areas for higher Rydberg states. We furthermore demonstrate that a conditional optical phase gate can be implemented by harvesting strong Rydberg atom interactions and SIT.

Q 36.3 Wed 14:30 f342

Vanishing-polarizability states of trappd Rydberg ions — •Fabian Pokorny, Chi Zhang, Gerard Higgins, and Markus Hennrich — Department of Physics, Stockholm University, 10691 Stockholm, Sweden

Trapped Rydberg ions are a novel approach for quantum information processing [1]. By combining the high degree of control of trapped ion systems with the long-range dipolar interactions of Rydberg atoms [2], fast entanglement gates may be realized in large ion crystals [1,3].

Recently, we carried out a controlled-phase gate in a two-ion crystal with a gate time of 700ns and more than 70% entaglement fidelity [4]. In order to implement such a gate in large or even multidimensional ion crystals, Rydberg states with vanishing polarizability may be crucial to mitigate otherwise considerable line-broadening caused by phonon-dependent energy shifts of bare Rydberg states [4, 5]. Here we report the realization of microwave-dressed Rydberg states with vanishing polarizability. We observed negligible energy shifts even in presence of excess micro-motion and performed Rabi oscillations between low-lying electronic states and vanishing-polarizability Rydberg states with only Doppler cooling.

[1] M. Müller, et al., New J. Phys. 10, 093009 (2008)
[2] D. Jaksch, et al., Phys. Rev. Lett. 85, 2208 (2000)
[3] F. Schmidt-Kaler, et al., New J. Phys. 13, 075014 (2011)
[4] C. Zhang, et al., arXiv:1908.11284 (2019)
[5] G. Higgins, et al., Phys. Rev. Lett. 123, 153602 (2019)

Q 36.4 Wed 14:45 f342

Strong spin-spin interactions and fast spin squeezing via Rydberg antiblockade dressing — •Weibin Li[1], Huaizhi Wu[1,2], and Shibiao Zheng[2] — [1]School of Physics and Astronomy, Unversity of Nottingham, Nottingham, UK — [2]Fujian Key Laboratory of Quantum Information and Quantum Optics and Department of Physics, Fuzhou University, Fuzhou 350116, People's Republic of China

We propose an antiblockade Rydberg dressing (ARD) scheme with the atomic ground state optically dressed to two coupled Rydberg states. By tuning the laser frequency in proximity to the antiblockade resonance, we obtain an interaction potential where the Rydberg-dressed ground states experience weakly repulsive interactions at short distances, while undergo strongly attractive interaction at certain, larger distances. The dissipative dynamics of interacting atoms subjected to ARD can be effectively described by a dephasing process with both one-body and two-body losses. The ARD with significantly enhanced dressed interactions can be then applied for fast implementation of a spin-echo spin squeezing, and offers a new way for the study of complex collective dynamics and the simulation of many-body spin models.

Q 36.5 Wed 15:00 f342

Ultrafast electron cooling in an expanding ultracold plasma — •Tobias Kroker[1,2], Mario Neundorf[1,2], Klaus Sengstock[1,2], Markus Drescher[1,2], Philipp Wessels[1,2], and Juliette Simonet[1,2] — [1]Zentrum für Optische Quantentechnologien (ZOQ), Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg

Local photoionization of a Bose-Einstein condensate with a femtosecond laser pulse provides access to an unprecedented regime of ultracold plasma. The accessible charge carrier density of $2{\cdot}10^{14}$ cm^{-3} enables the creation of micrometer-sized, strongly coupled plasma with an initial ion coupling parameter of $\Gamma = 4800$.

We create a tunable number of up to a few thousand charged particles by strong-field ionization of ^{87}Rb with an electron excess energy of 0.68 eV. Our dedicated experimental setup allows the measurement of the electronic kinetic energy distribution with meV resolution. We report on the direct observation of electron cooling from 5000 K to about 1 K in a few hundred nanoseconds.

The finite plasma size allows for charged particle tracing of the underlying plasma dynamics including mutual Coulomb coupling. The simulations are in excellent agreement with the measurements and provide access to the dynamics on sub-nanosecond timescales. We observe an ultrafast energy transfer of 50% of the excess energy from the electronic onto the ionic component within the first ten picoseconds.

Q 36.6 Wed 15:15 f342

Does a disordered Heisenberg spin system thermalize under explicit symmetry breaking? — •Titus Franz[1], Martin Gärttner[2], Adrien Signoles[3], Renato Ferracini Alves[1], André Salzinger[1], Annika Tebben[1], Sebastian Geier[1], David Grimshandl[1], Carlos Brandl[1], Clément Hainaut[1], Gerhard Zürn[1], and Matthias Weidemüller[1,4] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg — [3]Laboratoire Charles Fabry, Institut d'Optique Fraduate School, CNRS, Universite Paris-Saclay, 91127 Palaiseau cedex, France — [4]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

The far-from equilibrium dynamics of generic disordered systems is expected to show thermalization, but this process is yet not well understood and shows a rich phenomenology ranging from anomalously slow relaxation to the breakdown of thermalization. While this problem is notoriously difficult to study numerically, we can experimentally probe the relaxation dynamics in an isolated spin system realized by a frozen gas of Rydberg atoms. By breaking the symmetry of the Hamiltonian with an external field, we can identify characteristics of the long time magnetization, including a non-analytic behavior at zero field. These can be understood from mean field, perturbative, and spectral arguments. The emergence of these distinctive features allows to falsify whether the experiment satisfies Eigenstate Thermalization Hypothesis (ETH).

Q 36.7 Wed 15:30 f342

Quantum many-body dynamics of driven-dissipative Rydberg polaritons — •Tim Pistorius, Javad Kazemi, and Hendrik Weimer — Institut für theoretische Physik, Leibniz Universität Hannover, Deutschland

We study the propagation of Rydberg polaritons through an atomic medium in a one-dimensional optical lattice. We obtain an effective Hubbard model to describe the dark state polaritons under realistic assumptions. We analyse the driven-dissipative transport of polaritons through the system by considering a coherent drive on one side and by including the spontaneous emission of the metastable Rydberg state. Using a variational approch[1] to solve the many-body problem, we find strong antibunching of the outgoing photons despite the losses from the Rydberg state decay.

[1] H. Weimer, Phys. Rev. Lett. 114, 040402 (2015)

Q 36.8 Wed 15:45 f342

Distinguishability-induced quantum-to-classical transitions in many-body interference — •Christian Haen, Christoph Dittel, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Federal Republic of Germany

We study how partial particle distinguishability induces a transition from the quantum to the classical regime in interference scenarios of many, possibly interacting particles. By continuously tuning the particles' indistinguishability with respect to their internal degrees of freedom, we investigate the transition's statistical imprint – as revealed by interference visibilities [1] or the variance of on-site densities [2] – on the particles' dynamical evolution. Moreover, we assess the impact of a dynamical evolution of the internal degrees on the quantum-to-classical transition. Such internal dynamics may be induced by interactions with an environment and, thus, pave the way towards an open system theory of identical particles.

[1] C. Dittel, et al., arXiv, 1901.02810 (2019)
[2] T. Brünner, et al., *Phys. Rev. Lett.* **120**, 210401 (2018)

Q 37: Ultrashort Laser Pulses

Time: Wednesday 14:00–15:45 Location: f435

Q 37.1 Wed 14:00 f435

Millisecond wavelength tuning across hundreds of nanometers of a fiber optical parametric oscillator — •Tim Hellwig[1,2], Maximilian Brinkmann[1,2], and Carsten Fallnich[1] — [1]Institute of Applied Physics, University of Münster, Germany — [2]Refined Laser Systems GmbH, Münster, Germany

We present a mechanical delay-free tuning concept for optical parametric oscillators (OPO) removing the main barrier for high-speed switching between arbitrary wavelengths. The concept is based on dispersive matching of the repetition frequency change occurring during wavelength tuning of a pump laser to the associated change of repetition frequency in the OPO. We present a fiber-based optical parametric oscillator (FOPO), which is all electronically tunable within 5 ms. The FOPO was built from all-spliced components and the parametric gain was supplied by 50 cm of photonic-crystal fiber. The signal was all-electronically tunable from 780 to 970 nm with the corresponding idler wavelengths of 1150 to 1500 nm. For a conventional OPO this change in wavelength would be associated with a necessary mechanical delay of about 2 cm leading to the typical tuning times of at least several seconds. A second output provided access to 500 mW of pump pulse power usable for pump and probe experiments. With output powers of up to 200 mW for the signal wave, matching pulse durations of all outputs of 7 ps at 40 MHz and with excitation bandwidths of <12 cm-1 the presented system shows ideal performance, e.g., for efficient coherent Raman imaging.

Q 37.2 Wed 14:15 f435

Nonlinear Pulse Compression in a Dispersion-Alternating Fiber — •Niklas M. Lüpken[1] and Carsten Fallnich[1,2] — [1]Institute of Applied Physics, University of Münster, Corrensstraße 2, 48149 Münster, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, Enschede 7500 AE, The Netherlands

Based on the concept of alternating dispersion [1] we show improvements for nonlinearly compressing light pulses down to the few-cycle regime in a fiber chain with alternating dispersion.

Whereas the normally dispersive fiber segments generate bandwidth via self-phase modulation, the anomalously dispersive fiber segments recompress the broadened spectral bandwidth by an appropriate amount of group velocity dispersion. This approach avoids the use of free-space pulse compressors, the need for high pulse energies, or the precise control of the fiber length, whereas all these issues do represent drawbacks of current schemes. For shorter pulses, further pairs of fiber segments can be added with taking a trade-off between resulting peak power and unavoidable splicing losses into account.

In first experiments, nearly bandwidth-limited 25 fs pulses at 1560 nm were achieved from 80 fs input pulses, giving a pulse compression factor of 3.2. The use of a special anomalous dispersive fiber eliminated the impact of higher-order dispersion, such that a high spectral coherence was ensured. The results were in good agreement with nonlinear Schrödinger equation simulations, which also predicted that the concept is transferable to longer input pulses.

[1] Inoue et al., J. Light. Technol. 24, 2510 (2006).

Q 37.3 Wed 14:30 f435

Polarization gauge for few-cycle high intensity laser pulses — •Marius te Poel, Michael Stumpf, Julian Wegner, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

We present a gauge which allows for precise measurements of the polarization in lasers with ultrashort pulses and high power. Standard polarizers either tend to bleach out or are not selective enough in the required near-infrared range, and most of all, many of the employed effects are too wavelength-sensitive concerning the broad spectra of ultrashort pulse lasers. We present a new type of broadband polarization gauge which is based on Brewster-angle reflection at a fused silica mirror. This effect turns out to be almost constant over a bandwidth from 600 to 1000 nm. The device can be tuned to different wavelength ranges by adjusting the reflection angle and was used for detecting the exact direction of linearly polarization as well as the main axis of elliptically polarized light. We present the setup and characterization data of the PHASER sub-10-fs Ti:Sa-laser system in Düsseldorf. Furthermore, we discuss and present applications of the device.

Q 37.4 Wed 14:45 f435

A dispersion-free Attenuator for Ultra-short Laser Pulses — •Julia Kunzelmann, Julian Wegner, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich Heine Universität Düs-

seldorf

Lasers play an important role in technology and science. For many applications, the power and intensity must be accurately adjusted. With few-cycle laser pulses, a main challenge consists in varying the laser pulse intensity without changing any other parameter, like the temporal pulse shape or the focus spot size. We developed a new fully reflective pulse attenuator which is based upon properly shaped thin metal layers. This decreases the pulse energy by several orders of magnitude in many fine steps while keeping the other parameters constant.

We present the setup of our device together with simulations of the reflective layers and various measurements which show that other parameters are not affected. Furthermore, a few examples are given in which the new attenuator has been applied fruitfully in laser-matter interaction experiments.

Q 37.5 Wed 15:00 f435

Common pulse retrieval algorithm: a universal and accurate method to retrieve ultrashort pulses — •Nils C. Geib[1], Heiko Knopf[1,2], Gia Quyet Ngo[1], Thomas Pertsch[1,2], and Falk Eilenberger[1,2] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, Albert-Einstein-Str. 15, 07745 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Center for Excellence in Photonics, Albert-Einstein-Str. 7, 07745 Jena, Germany

Many ultrashort laser pulse measurement schemes such as frequency-resolved optical gating (FROG), interferometric FROG, dispersion scan, or time-domain ptychography require a specific, iterative algorithm to retrieve pulse amplitude and phase from the measurement. In this work, we present a common pulse retrieval algorithm (COPRA) that can be applied on a broad class of measurements, including but not limited to the aforementioned ones. It can also be universally applied to measurements for which no specific retrieval algorithm was known before. We test our approach on numerical and experimental data and show that it is reliable and accurate in the presence of Gaussian measurement noise. Furthermore, we discuss how to obtain reliable uncertainty estimates on the retrieved pulses.

Q 37.6 Wed 15:15 f435

Spontaneous Four-Wave Mixing Light Source in Silicon Nitride Waveguide for Coherent Raman Scattering — •Niklas M. Lüpken[1], Thomas Würthwein[1], Klaus-J. Boller[2,1], and Carsten Fallnich[1,2] — [1]Institute of Applied Physics, University of Münster, Corrensstraße 2, 48149 Münster, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, Enschede 7500 AE, The Netherlands

Silicon nitride (Si_3N_4) waveguides offer an on-chip platform with a small footprint, a high nonlinear refractive index, and tight mode confinement. Therefore, nonlinear processes such as four-wave mixing (FWM) or supercontinuum generation can be driven very efficiently, e.g., for broadband optical frequency combs [1].

Within this contribution, we present a light source for coherent anti-Stokes Raman scattering (CARS) microscopy, with the potential to be set up as an all-integrated device, based on spontaneous FWM in Si_3N_4 waveguides with only a single ultrafast fiber-based pump source at 1030 nm wavelength. During the FWM process in the Si_3N_4 waveguide, broadband signal and idler pulses are generated, such that the idler pulses and the residual pump pulses can be used for CARS measurements, enabling chemically selective and label-free imaging over the entire fingerprint region by addressing vibrational energies from $500\,\mathrm{cm}^{-1}$ to $1800\,\mathrm{cm}^{-1}$.

[1] Porcel et al., Opt. Express 25, 1542 (2017).

Q 37.7 Wed 15:30 f435

Triggering Dispersive Waves via XPM in Si_3N_4 Integrated Optical Waveguides — •Maximilian Timmerkamp[1], Niklas M. Lüpken[1], and Carsten Fallnich[1,2] — [1]Institute of Applied Physics, University of Münster, Corrensstraße 2, 48149 Münster, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, Enschede 7500 AE, The Netherlands

Supercontinua are of high interest in current research due to their broad bandwidth and high brightness enabling a manifold of applications in, e.g., spectroscopy or precision metrology.

Typically, a higher-order soliton is formed during the supercontinuum generation process, which is perturbed by higher-order dispersion leading to the fission into fundamental solitons, each radiating energy into a dispersive wave [1]. These dispersive waves propagate in the same transverse mode as the corresponding solitons.

In multi-mode waveguides, nonlinear coupling allows for energy exchange between transverse modes. In this contribution, we show an experimental evidence of soliton dynamics in multi-mode silicon nitride (Si_3N_4) waveguides, where a dispersive wave is generated in a different transverse mode than the pump mode, triggered by intermodal cross-phase modulation. These intermodal soliton dynamics lead to new phase-matching conditions, enabling the generation of new frequencies.

[1] Roy et al., Phys. Rev. A 79, 023824 (2009)

Q 38: Quantum Effects (QED) I

Time: Wednesday 14:00–16:00 Location: f442

Q 38.1 Wed 14:00 f442

Optical Signatures of Quantum Vacuum Nonlinearities in the Strong Field Regime — •Leonhard Klar[1,2], Felix Karbstein[1,2], and Holger Gies[1,2] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany

Quantum electrodynamics (QED) is the most precisely tested quantum field theory. Nevertheless, particularly in the high-intensity regime it predicts various phenomena, that so far have not been directly accessible in experiments, such as light-by-light scattering phenomena induced by quantum vacuum fluctuations. Our focus is on all-optical signatures of quantum vacuum effects which can be probed in high-intensity laser experiments with state-of-the-art technology. More specifically, we aim at identifying experimentally viable scenarios where the signal photons encoding the signature of QED vacuum nonlinearity can be distinguished from the large background of the driving laser photons.

We present a promising setup allowing to find signal photons discernible from the background. To this end, we envision the collision of several tightly focused high-intensity laser beams, which are assumed to be generated by two lasers and suitable frequency doubling, and identify a superposition scheme of these lasers that induces prominent signal properties. A key mechanism consists in producing a narrow scattering center. We calculate the differential number of signal photons attainable in this field configuration analytically.

Q 38.2 Wed 14:15 f442

Quantum and classical phase-space dynamics of a free-electron laser — •C. Moritz Carmesin[1,2], Peter Kling[2,3], Enno Giese[2], Roland Sauerbrey[2], and Wolfgang P. Schleich[2,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, 89069 Ulm, Germany — [3]Institute of Quantum Technologies, German Aerospace Center (DLR), Söflinger Straße 100, D-89077 Ulm, Germany

In a quantum mechanical description of the free-electron laser (FEL) the electrons jump on discrete momentum ladders [1], while they follow continuous trajectories inside a separatrix in phase space according to the classical description. We show that it is not sufficient to have many momentum levels involved in order to observe the transition from quantum to classical dynamics. Only if additionally the initial momentum spread of the electron beam is larger than the quantum mechanical recoil caused by the emission and absorption of photons, the quantum dynamics in phase space resembles the classical one. Beyond these criteria, quantum signatures of averaged quantities like the FEL gain might be washed out. Our results [2] are not limited to the highly relativistic electron energies of FELs but are also applicable to different setups with electron-light interaction at lower electron energies.

[1] P. Kling et al. 2015 *New J. Phys.* **17** 123019
[2] C. M. Carmesin et al. *arXiv* 1911.12584

Q 38.3 Wed 14:30 f442

Numerical simulation of non-linear Compton scattering in counter-propagating laser beams — •Qingzheng Lyu, Erez Raicher, Karen Z. Hatsagortsyan, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The non-linear Compton scattering process of an electron in counter-propagating laser beams is considered. Employing the semiclassical operator approach [Sov. Phys. JETP 26, 854 (1968)], we can obtain the emission spectrum of an ultra-relativistic electron propagating in the counter-propagating laser beams. Because of the ultra-relativistic energy of the particle, the emission can be approximated by the classical trajectory of the particle instead of the full wave function in the background field. We investigate the spectrum for various laser and particle parameters. In particular, the validity conditions of the local constant field approximation, which is relevant for simulating QED processes in laser-plasma interactions, are examined in this more general situation.

Q 38.4 Wed 14:45 f442

X-ray coherent control with nuclear resonances — •Adriana Pálffy and Xiangjin Kong — Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

The resonant interaction between x-ray photons and nuclei is one of the most exciting subjects of the burgeoning field of x-ray quantum optics [1]. A resourceful platform used so far are thin-film x-ray cavities with embedded layers or Mössbauer nuclei such as ^{57}Fe. Interesting physics was reported in such thin-film cavities with several nuclear layers. For instance, the first observation of Rabi oscillations of an x-ray photon between two resonant 57 Fe-layers embedded in two coupled cavities was predicted theoretically and confirmed experimentally [2].

Here we present a new quantum optical model based on the classical electromagnetic Green's function that has been developed to investigate theoretically the nuclear response inside the x-ray cavity. The model is versatile and provides an intuitive picture about the influence of the cavity structure on the resulting spectra. Benchmarking with simulations using the semiclassical Parratt formalism and other semi-classical or quantum models is performed. In this context, we discuss our results for increasing complexity of layer structures.

[1] B. Adams *et al.*, J. Mod. Opt. 60, 2 (2013).
[2] J. Haber *et al.*, Nature Photonics 11, 720 (2017).

Q 38.5 Wed 15:00 f442

Attractive force between equally-charged ions — •Johannes Fiedler[1] and Stefan Yoshi Buhmann[1,2] — [1]University of Freiburg, Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Universität Freiburg, Freiburg, Germany

The multipole expansion of the electric field for an ion yields the charge, dipole, quadrupole and higher order contributions [1]. Beyond these classical interactions, fluctuations of these quantities play a role when considering interactions between such particles, which manifest in the forms of the van der Waals and Keesom forces [2]. Typically, the Coulomb interaction dominates the total force. The dominating effect upon adding an environmental medium is the damping of the interaction caused by its refractive index. This screening depends on the spectrum of the medium, which leads to differing orders of dominant interactions. We will present a theory of medium-assisted intermolecular interactions [3] and illustrate scenarios where the higher order forces dominate the Coulomb interactions.

[1] J. D. Jackson, Classical electrodynamics, 3rd ed. (Wiley, New York, NY, 1999).
[2] J.N. Israelachvili, Intermolecular and Surface Forces, 3rd ed. (Academic Press, Waltham, MA, 2011).
[3] J. Fiedler, S.Y. Buhmann, submitted to PCCP (2019).

Q 38.6 Wed 15:15 f442

Appearance of a half-integer power in the small-distance expansion of the Casimir energy — •Benjamin Spreng[1], Michael Hartmann[1], Paulo Maia Neto[2], and Gert-Ludwig Ingold[1] — [1]Institut für Physik, Universität Augsburg, Germany — [2]Instituto de Física, Universidade Federal do Rio de Janeiro, Brazil

The proximity force approximation (PFA) is a widely used tool to study the Casimir interaction in experiments between for example a plane and a sphere. Within the PFA, the finite curvature of the sphere is accounted for by averaging the Casimir energy of parallel plates over the local distances of the two bodies. The approximation becomes valid when the ratio L/R is small where L is the distance of the sphere's surface to the plane and R is the sphere's radius.

At zero temperature, leading corrections beyond the PFA are linear in L/R and have been studied extensively. Here, we are interested in the expansion of the Casimir energy beyond the linear term. If applicable, the method of the derivative expansion suggests a correction quadratic in L/R. However, our numerically exact computation of the Casimir energy strongly suggests a correction of the form $(L/R)^{3/2}$. This result is not limited to specific material classes and can also be found for other geometries such as for two spheres (with R replaced by the effective radius), and a cylinder opposite to a plane. A mechanism explaining the emergence of the half-integer power is provided.

Q 38.7 Wed 15:30 f442

Quantum radiation in dielectric media with dispersion and dissipation — •Sascha Lang[1,2], Ralf Schützhold[1,3], and William G. Unruh[4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Fakultät für Physik, Universität Duisburg-Essen, 47057 Duisburg, Germany — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany — [4]Department of Physics and Astronomy, University of British Columbia, Vancouver BC V6T 1Z1, Canada

By a generalization of the Hopfield model, we construct a microscopic Lagrangian describing a dielectric medium with dispersion and dissipation. This facilitates a well-defined and unambiguous *ab initio* treatment of quantum electrodynamics in such media, even in time-dependent backgrounds. As an example, we calculate the number of photons created by switching on and off dissipation in dependence on the temporal switching function. This effect may be stronger than quantum radiation produced by variations of the refractive index $\Delta n(t)$ since the latter are typically very small and yield photon numbers of order $\Delta n^2(t)$. As another difference, we find that the partner particles of the created medium photons are not other medium photons but excitations of the environment field causing the dissipation (which is switched on and off).

Q 38.8 Wed 15:45 f442

Quantum radiation reaction in aligned crystals beyond the local constant field approximation. — •Tobias Wistisen and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland

When an electron or a positron hits a crystal target with a small angle of incidence with respect to a crystal symmetry axis or plane, it experiences a strong electromagnetic field. If the particle energy is high enough, one can reach the QED critical (Schwinger) field $E_{\mathrm{cr}} = m^2c^3/(\hbar e) \approx 1.3 \times 10^{18}$ V/m in the rest frame of the particle. Quantum radiation reaction corresponds to the emission of multiple photons in this regime. In [1] we investigated this using a positron beam with 180 GeV directed along a crystalline axis in Silicon. The radiation emission process could then be approximated as if taking place in a constant field, in each moment of time, often called the local constant field approximation (LCFA). For lower particle energies this approximation is no longer applicable. With this in mind, a new theoretical model based on a semiclassical approach for calculating radiation emission in the quantum regime beyond the use of the LCFA was devised. In 2017 an experiment, at lower energies, was carried out at the CERN H4 beamline, and we compared the experimentally measured photon emission spectra to the LCFA model, and the new theoretical model. It is seen that the new approach is in convincing agreement with the data, while the LCFA is in disagreement [2].

[1] T.N. Wistisen et. al. Nat. Commun., 9(1):795. Feb. 2018.
[2] T.N. Wistisen et. al. Phys. Rev. Research 1, 033014. Oct. 2019

Q 39: Posters: Quantum Optics and Photonics III

Time: Wednesday 16:30–18:30 Location: Empore Lichthof

Q 39.1 Wed 16:30 Empore Lichthof

A Distribution Board for an Ultra-stable Transportable Clock Laser — •Eileen Annika Klocke[1], Sofia Herbers[1,2], Lenard Pelzer[1], Uwe Sterr[1], Piet Oliver Schmidt[1,2,3], and Chrstian Lisdat[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, c/o Leibniz Universität Hannover, Hannover, Germany — [3]Institut of Quantum Optics, Leibniz Universität Hannover, Hannover, Germany

Ultra-stable interrogation lasers are key components in optical clocks. These clocks are used to investigate tests of fundamental physics or determine height differences between distant points in relativistic geodesy. Many applications require a transportable system that cannot rely on a well-controlled laboratory environment.

Here we present an interrogation laser system, composed of a laser, a cavity to frequency stabilize the laser, and a light distribution board. This system is designed for a transportable optical Al^+ quantum logic clock. The thermal noise of the cavity components is expected to limit the fractional frequency stability of the laser to values below 10^{-16}.

For clock operation, the laser light is split up on the distribution board, and sent via path length stabilized optical fibers to the atomic reference, the cavity and the frequency comb. The compact and robust distribution board ensures the transportability as well as a stable and accurate frequency transfer.

Q 39.2 Wed 16:30 Empore Lichthof

Investigation of zinc as a candidate for optical clocks — •David Röser, Maya Büki, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

The development of modern optical clocks has lead to frequency references with a precision level down to about 10^{-18} . Much effort in current development is put into downsizing existing clocks to make them transportable while keeping their precision.

We investigate zinc atoms as a novel platform. Zinc provides metastable states and thus a suitable level structure with a narrow $^1S_0$ to $^3P_1$ intercombination line and a doubly forbidden clock transition in the UV range.

Its low sensitivity to blackbody radiation shifts and the potential for miniaturization could allow for clock operation outside of laboratory environments. A clock laser is currently developed by frequency quintupling a diode laser at telecom c-band wavelength enabling the direct distribution of the clock signal via optical fibers.

We report on different concepts of constructing a clock based on zinc spectroscopy and the status of our experiment.

Q 39.3 Wed 16:30 Empore Lichthof

Steady-state superradiance for active optical clocks — •Francesca Fama[1], Sheng Zhou[1], Shayne Bennetts[1], Chun-Chia Chen[1], Rodrigo Gonzalez-Escudero[1], Benjamin Pasquiou[1], Florian Schreck[1], and the iqClock consortium[2] — [1]Institute of Physics, University of Amsterdam, Amsterdam, The Netherlands — [2]www.iqclock.eu

Superradiant lasers have been proposed as a next generation optical atomic clock for precision measurement, metrology, quantum sensing and exploration of new physics [1]. Recently, a pulsed superradiant laser was demonstrated using the ^{87}Sr clock transition [2], but a clock with millihertz stability requires steady-state operation.

We will describe the new machine that we are constructing, which aims to produce a steady-state superradiant laser for future time standards. The architecture is an improvement of our earlier work [3,4,5] where we have now demonstrated ideal sources for pumping a steady-state superradiant laser. We have produced a steady-state atomic beam guided by a dipole laser with a radial temperature of 1μK, a phase-space density of 10^{-4} and a flux of 3x10^7 ^{88}Sr/s. These performances have been explored also by using the ^{87}Sr isotope, which is of particular interest for clocks.

[1] Meiser et al., PRL 102, 163601 (2009). [2] Norcia et al., Sci Adv 2, 10, e1601231 (2016). [3] Bennetts et al., PRL 119, 223202 (2017). [4] Chen et al., PRA, 100, 023401 (2019). [5] Chen et al., arXiv:1907.02793 (2019).

Q 39.4 Wed 16:30 Empore Lichthof

Highly stable, compact components for a transportable Al^+/Ca^+ quantum logic optical clock — •Benjamin Kraus[1,4], Stephan Hannig[1,4], Moritz Mihm[2], Ortwin Hellmig[3], Patrick Windpassinger[2], and Piet O. Schmidt[1,4] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Johannes Gutenberg-Universität Mainz, 55122 Mainz, Germany — [3]Universität Hamburg, 20148 Hamburg, Germany — [4]DLR-Institute for Satellite Geodesy and Inertial Sensing, c/o Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

A transportable optical ion clock requires a compact and robust setup. These requirements are fulfilled by fiber-coupled components and rigid Zerodur®-based breadboards[1]. We present a distribution board, where light required for Ca^+ ionization, cooling and repumping is coupled into an LMA fiber. Moreover, we present a fiber-coupled length-stabilized source for Al^+ clock light of 267 nm, consisting of two subsequent single-pass SHG stages. Finally, we report on the development of fiber-coupled single and double-pass AOMs for that wavelength.

1. M. Mihm, "ZERODUR® based optical systems for quantum gas experiments in space," Acta Astronautica 159, 166*169 (2019).

Q 39.5 Wed 16:30 Empore Lichthof

Spin squeezing can only improve clocks with small atom number — •Marius Schulte[1], Christian Lisdat[2], Piet O. Schmidt[2,3], Uwe Sterr[2], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover — [2]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig — [3]Institute for Quantum Optics, Leibniz University Hannover

We show that the stability of an optical atomic clock can not be improved by spin squeezed states for ensembles above a critical particle number as in this case, the optimum stability is completely determined by the noise and the limited coherence time of the interrogation laser. Our results apply to the common case of cyclic Ramsey interrogations on a single atomic ensemble with dead time between each measurement. The combination of analytical models for projection noise, dead time noise (Dick effect) and laser phase noise allows quantitative predictions of the critical particle number and the optimal clock stability for a given dead time and laser noise. Our analytical predictions are confirmed by numerical simulations of the closed servo loop of an optical atomic clock. This work was supported by SFB 1227 'Dq-mat'. arXiv:1911.00882

Q 39.6 Wed 16:30 Empore Lichthof

Resonance fluorescence of trapped Be^{9+} ions — •Aleksei Konovalov and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

We theoretically analyse the resonance fluorescence of a single Be^9+. We consider the transition $2s_{1/2} \rightarrow 2p_{3/2}$ including the hyperfine structure and analyse the photon signal using the coarse-grained master equation developed in [1], which consistently includes interference terms between parallel dipolar transitions. We discuss the effect of these interference terms on the spectroscopic signal.

[1] Andreas Alexander Buchheit and Giovanna Morigi, PHYSICAL REVIEW A 94, 042111 (2016).

Q 39.7 Wed 16:30 Empore Lichthof

Progress towards an indium multi-ion clock — •Hartmut Nimrod Hausser, Tabea Nordmann, Jan Kiethe, Leon Schomburg, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Multi-ion clocks face many challenges: One of the biggest challenge is the strong electric field gradient leading to a relatively high electronic quadrupole shift. For such a clock $^{115}In^+$ is an ideal candidate offering an extremely small electric quadrupole moment, a narrow-line clock transition, a transition where it is directly detectable and low systematic shifts [1]. Here we present the progress towards an indium multi-ion clock. We show the first steps towards automatization like automated fiber coupling and slave relocking. A small chip-based linear Paul trap is used to trap $^{115}In^+$ and $^{172}Yb^+$ in a mixed Coulomb crystal [2]. We show the implementation of a new detection system where both species can be imaged simultaneously. We present further investigations on polarization-maintaining UV fibers to deliver a Gaussian-like, intensity- and polarization-stable beam to the ions at 230.6 nm and 236.5 nm, which are the detection and clock transition wavelength of $^{115}In^+$, respectively.

This project has received funding from the European Metrology Programme for Innovation and Research (EMPIR) co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme (Project No. 18SIB05 ROCIT).

[1] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012).
[2] J. Keller et al., *Phys. Rev. A.* **99**, 013405 (2019).

Q 39.8 Wed 16:30 Empore Lichthof

Laser light shaping and control for precision spectroscopy with ions — •Robin L. Stampa, André P. Kulosa, Chih-Han Yeh, Dimitri Kalincev, Henning A. Fürst, Laura S. Dreissen, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Coherent excitation of forbidden transitions, as used for example in optical clocks, sets stringent requirements on the ultra-stable probe laser. To provide sufficient power, the light source needs to be amplified. This can be accomplished by a slave diode laser. Here, we report on automatic re-locking of a slave laser at 411 nm employing a microcontroller for nearly 24/7 operation [1]. To reach the accuracy of optical clocks with efficiently reduced measurement time, simultaneous precision spectroscopy of forbidden transitions in trapped multi-ion Coulomb crystals can be advantageous. This requires equally distributed laser intensity onto the ions. We investigate different methods for this, while taking flexibility, reliability, and ion-light interaction efficiency into account, using either a spatial light modulator, micromirror arrays or holographic phase plates. Our result will not only be of interest for the operation of optical multi-ion clocks, but also for the study of dynamics in multi-ion Coulomb crystals [2]. Furthermore, it can be an important tool for the test towards Local Lorentz Symmetry breaking with multiple ions [3].

[1] B. Saxberg et al., *Rev. Sci. Instrum.* **87**, 063109 (2016). [2] J. Kiethe et al., *Nat. Commun.* **8**, 15364 (2017). [3] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018).

Q 39.9 Wed 16:30 Empore Lichthof

An ultra-stable resonator with a fundamental instability of 3×10^{-17} — •Steffen Sauer[1], Sebastian Häfner[2], Dominika Fim[1], Nandan Jha[1], Waldemar Friesen-Piepenbrink[1], Klaus Zipfel[1], Thomas Legero[2], Wolfgang Ertmer[1], Uwe Sterr[2], and Ernst Rasel[1] — [1]Institut für Quantenoptik, Hannover, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Most of today's accurate and stable optical clocks are limited by the so-called Dick noise, where the coherence length of the interrogation laser plays the decisive role. Therefore we are setting up a new 48 cm ULE resonator at room-temperature with crystalline mirror coatings [1] at 1550 nm. We expect a fundamental instability, caused by the Brownian motion in the material, of 3×10^{-17}, which is comparable to the most stable resonators in the world today. After the construction and characterization against the single-crystal silicon resonators at PTB [2], the ultra-stable resonator is to be used as ultra-stable local oscillator for the magnesium lattice clock at IQ, Hannover. The stability will be transmitted via a femtosecond fiber comb to the interrogation laser at 916 nm which currently operates with an instability of 4×10^{-16} in 1 s. On this poster we report on the progress and characterization of our ultra-stable local oscillator. This work has received funding under Germany's Excellence Strategy-EXC-2123/1 ("QuantumFrontiers").

[1] Cole et al., Nature Photonics **7**, 644-650 (2013)
[2] Matei et al., Phys. Rev. Lett. **118**, 263202 (2017)

Q 39.10 Wed 16:30 Empore Lichthof

Segmented linear multi-ion traps for a next generation of transportable high-precision optical clocks — •Florian Köppen[1], Hendrik Siebeneich[1], Pedram Yaghoubi[1], Michael Johanning[1], Alexandre Didier[2], Malte Brinkmann[2], Stefan Brakhane[3], Tanja Mehlstäubler[2], Dieter Meschede[3], and Christof Wunderlich[1] — [1]Naturwissenschaftlich-Technische Fakultät, Department Physik, Universität Siegen, Walter-Flex-Str. 3, 57072 Siegen, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [3]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany

Trapped atomic ions are well suited for realizing accurate and stable optical clocks. The *opticlock* consortium [1] develops a compact transportable optical clock for non-specialist users, utilizing a quadrupole transition with a wavelength near 436 nm in a single $^{171}Yb^+$ ion, with a projected uncertainty of order 10^{-16}. Based on this system we develop a next-generation optical clock along [2] combining the accuracy of a multiple ion frequency standard with the compactness of the *opticlock*-demonstrator. For this purpose we use a segmented four layer ion trap and a compact vacuum interface, allowing for excellent optical access. We will present details of the chip carrier, chamber and cuvette, as well as the optical, electrical and software design.

[1] https://www.opticlock.de; *opticlock* is supported by the bmbf under grant no. 13N14385.
[2] J. Keller et al., Phys. Rev. A99, 013405 (2019)

Q 39.11 Wed 16:30 Empore Lichthof

Accelerating magnetic field sensing using optimized pulses on NV centers — •Jan Thieme, Ricky-Joe Plate, Josselin Bernardoff, Daniel Basilewitsch, Christiane Koch, and Kilian Singer — Institut für Physik, Uni Kassel, Deutschland

Estimation of physical parameters, such as a magnetic field on a spin, are very often done using the Ramsey method of separated fields for its utmost simplicity and optimality. More sophisticated scheme, using resources such as entanglement to enhance sensitivity achieve records for long measurement times.

We are looking for improvement using pulse sequences that decrease measurement time at the cost of a limited resolution. Indeed, optimal control tools can find pulse shapes, such as a square response - within limitation on hardware -, as a function of detuning which changes the way a resonance search is performed. The protocol's sensitivity can be evaluated using standard tools of estimation theory, in particular the Fisher information.

Such a protocol could for instance allow imaging to be performed on shorter timescales.

Q 39.12 Wed 16:30 Empore Lichthof

Perspectives for fundamental experiments with nanostructured optical cavities: From thermal quanta to general relativity — •Johannes Dickmann[1,2,3], Steffen Sauer[1,4], Sebastian Ulbricht[1,2,3], Robert Alexander Müller[1,2,3], Jan Meyer[1,2,3], Tim Käseberg[2], Mariia Matiushechkina[1,4], Andrey Surzhykov[1,2,3], Ernst Maria Rasel[1,4], Michèle Heurs[1,4,5], and Stefanie Kroker[1,2,3] — [1]Exzellenzcluster QuantumFrontiers, Hannover and Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Technische Universität Braunschweig, Braunschweig, Germany — [4]Leibniz Universität Hannover, Hannover, Germany — [5]Max Planck Institute for Gravitational Physics, Hannover, Germany

High finesse optical cavities are the key ingredients for the world's most precise measurements. These range from optical atomic clocks via quantum optomechanics up to gravitational wave detection. Improving the stability of optical cavities paves the way for the next frontiers of scientific discoveries. Recent mirror technologies based on nanostructured surfaces are very promising to enhance the stability of optical cavities towards a range where quantum effects and the influence of gravity become apparent. We present theoretical considerations on gravitational effects on the optical output of ground-based cavities as well as discussions on thermal fluctuations using thin membranes in cavities. Proposed experimental configurations including design guidelines to measure temperature via thermal fluctuations and to test general relativity on earth complement this contribution.

Q 39.13 Wed 16:30 Empore Lichthof

Laser system and imaging optics for producing, cooling and detecting a $^9Be^+$ ion in a cylindrical Penning trap — •Frederik Jacobs[1], Teresa Meiners[1], Johannes Mielke[1], Matthias Borchert[1,3], Julian Pick[1], Juan M. Cornejo[1], Malte Niemann[1], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch Technische Bundesanstalt, Braunschweig — [3]Ulmer Fundamental Symmetries Laboratiory, RIKEN, Wako, Saitama 351-0198, Japan

The BASE collaboration aims for high precision measurements of the proton's and antiproton's g-factor to support tests of CPT invariance with baryons. We discuss an experimental setup for the development of laser-based manipulation techniques amenable to (anti-)protons trapped in a cylindrical Penning trap. The setup focuses on sympathetic cooling with a co-trapped laser-cooled beryllium ion.

Here, we present the optical setup for producing, cooling, and detecting a beryllium ion. The Doppler cooling beam is currently sent into the trap at a 45° angle with respect to the symmetry axis in order to cool both the radial and axial motional modes of the beryllium ion at the same time. We discuss an alternative approach based on an axial cooling beam and indirect cooling of the radial motional modes using only axialisation.

Q 39.14 Wed 16:30 Empore Lichthof

High-Q monolithic inertial sensors for seismic control in gravitational wave detectors — Sina Maria Köhlenbeck[1,2], •Jonathan Carter[1,2], Gerhard Heinzel[1,2], and Oliver Gerberding[3] — [1]MPI für Gravitationsphysik, Callinstr. 38, 30167 Hannover — [2]Institut für Gravitationsphysik, Leibniz Universität Hannover, Callinstr. 38, 30167 Hannover — [3]Institut für Experimentalphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Seismic noise is one of the noise sources limiting the performance of earth-bound interferometric gravitational wave detectors. To enhance the operation time of future detectors, new sensors for active stabilization of the mirror displacement are required. Commercial sensors are heavy, bulky and not vacuum compatible, where our design, based on an all-glass opto-mechanic oscillator with an interferometric read-out, resolves these constraints. The concept, design and first tests of the oscillators will be presented.

Q 39.15 Wed 16:30 Empore Lichthof

Rydberg quantum optics in an ultracold Rubidium gas — •Hannes Busche, Nina Stiesdal, and Sebastian Hofferberth — University of Southern Denmark, Odense, Denmark

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons enables the realization of optical nonlinearities which can modify light on the level of individual photons. This approach forms the basis of a growing Rydberg quantum optics toolbox, which already contains photonic logic building-blocks such as single-photon sources, switches, transistors, and two-photon gates.

Here we discuss how we experimentally implement a 1d chain of Ryderg superatoms, each formed by an individually trapped atomic cloud containing ca. N=10000 atoms. With this system we can study the dynamics of single two level systems strongly coupled to quantized propagating light fields. The directed emission of the superatoms back into the probe mode makes this free-space chain of superatoms identical to emitters coupled to a 1d optical waveguide, thus realizing a cascaded quantum system coupled to a single probe mode.

Q 39.16 Wed 16:30 Empore Lichthof

Rydberg quantum optics in ultracold Ytterbium gases — •José Navarrete, Thilina Senaviratne, Mohammad Noaman, and Sebastian Hofferberth — University of Southern Denmark, Odense, Denmark

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons enables the realization of optical nonlinearities which can modify light on the level of individual photons. In our group, we explore this novel approach to realize effective photon-photon interaction in multiple experiment setups and following two complementary approaches employing Rydberg polaritons and superatoms.

Here we present progress with our new Rydberg quantum optics experiment utilizing ultracold Ytterbium as optical medium. The specific goal of this new setup is to study the interactions between a large number of Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. Employiing for the first time ultracold Ytterbium, an alkaline-earth-like element, for Rydberg quantum optics experiments offers unique advantages towards this goal. We discuss details of our experimental implementation and report on the progress towards observation of few-photon nonlinearities in Yb.

Q 39.17 Wed 16:30 Empore Lichthof

Interacting Polaritions in a Rydberg EIT Medium — •Annika Tebben[1], André Salzinger[1], David Grimshandl[1], Carlos Brandl[1], Sebastian Geier[1], Titus Franz[1], Nithiwadee Thaicharoen[1], Clément Hainaut[1], Gerhard Zürn[1], Thomas Pohl[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK 8000 Aarhus C, Denmark — [3]National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, and CAS Center for Excellence and Synergetic Innovation Center in Quantum Information and Quantum Physics, Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

Polaritons, which are superpositions of a photonic and a collective atomic excitation, can interact via dressing to long-range interacting Rydberg states. This opens the possibility for investigating many-body physics with photons as well as strongly correlated states of light. For observing these effects strong interactions or large interaction times are needed. However, the latter is usually limited by the propagation time of the slow light polariton through the medium under conditions of electromagnetically induced transparency (EIT). We show that this limitation can be overcome by generating propagation free photonic excitations, so called stationary light polaritons, and explain how this kind of polaritons can serve to engineer strongly interacting many body systems.

Q 39.18 Wed 16:30 Empore Lichthof

Rydberg excitation of trapped ions for quantum simulation and computation — •Justas Andrijauskas[1,2], Jonas Vogel[1], Arezoo Mokhberi[1], and Ferdinand Schmidt-Kaler[1,2] — [1]Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

Trapped ions excited to Rydberg states combines high controllability of trapped ions with high polarisability and long lifetimes of Rydberg states[1,2]. We present the two step excitation of trapped $^{40}Ca^{+}$ ions to Rydberg states, using laser systems at 213nm and 287nm wavelengths. Laser beams are configured in counter-propagating manner such that the line broadening due to the Doppler effect is mitigated. The ion trap is operated at 14.6 MHz drive frequency and features secular frequencies near 600, 1200, 1600 kHz. We also discuss our experimental results obtained by spectroscopy of S and D series in order to optimize the micromotion control, determine line shapes and quantum defects[3] and compare to theory predictions.

[1] Feldker et al., Phys. Rev. Lett. 115, 173001(2015)
[2] Higgins et al., Phys. Rev. Lett. 119, 220501 (2017)
[3] Mokhberi et al. J. Phys. B 52, 214001 (2019)

Q 39.19 Wed 16:30 Empore Lichthof

Towards a Photon-Photon Quantum Gate Using Rydberg-Interactions in an Optical Resonator — •Thomas Stolz, Steffen Schmidt-Eberle, Lukas Husel, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

We recently realized a photon-photon π-phase gate based on free-space Rydberg EIT in an ultracold atomic ensemble [1]. The performance in terms of efficiency and postselected fidelity is limited by dephasing resulting from the interaction between the Rydberg electron and surrounding ground-state atoms. The dephasing rate can be much reduced by working at lower atomic density [2]. To keep the gate operational in this regime, we plan to place the ensemble inside a moderate-finesse optical resonator [3,4]. We report on experimental progress toward this goal.

[1] D. Tiarks et al. Nat. Phys. **15**, 124 (2019). [2] S. Schmidt-Eberle et al. arXiv:1909.00680. [3] Y. M. Hao et al. Sci. Rep. **5**, 10005 (2015). [4] S. Das et al. PRA **93**, 040303 (2016).

Q 39.20 Wed 16:30 Empore Lichthof

Ultrafast Ionization of a BEC: Highly Charged to Neutral Microplasma — •Mario Neundorf[1,2], Tobias Kroker[1,2], Julian Fiedler[1], Julia Bergmann[1], Markus Drescher[1,2], Klaus Sengstock[1,2], Philipp Wessels[1,2], and Juliette Simonet[1,2] — [1]Zentrum für Optische Quantentechnologien (ZOQ), Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg

In our experiment, we combine a ^{87}Rb Bose-Einstein condensate with femtosecond laser pulses to investigate collective non-equilibrium dynamics after locally ionizing parts of the atomic cloud.

The quantum gas machine allows to simultaneously detect atoms, ions and electrons after photoionization and resolves the kinetic energy of the charged particles.

By using a micrometer sized waist for the ionizing laser, we can trigger ultracold plasmas with variable particle numbers. Tuning the initial

kinetic energy of the ionization products allows bridging from highly charged to neutral plasmas.
The combination of a well-controlled target with negligible initial kinetic energy and the small system size allows us to simulate the underlying dynamics with charged particle tracing. This provides an excellent model system to study the experimentally demanding density regime between ionized solid-state nanoclusters and ultracold neutral plasma.

Q 39.21 Wed 16:30 Empore Lichthof

Towards a strontium Rydberg laser for quantum simulation with tweezer arrays — •Thies Plassmann, Shayne Bennetts, Alex Urech, Benjamin Pasquiou, Robert Spreeuw, and Florian Schreck — Institue of Physics, University of Amsterdam, Amsterdam, The Netherlands

We are developing a broadly tunable CW UV-laser system for exciting Rydberg states in strontium atoms. Arrays of single atoms in tweezer traps using Rydberg states for long-range interactions has proven to be a powerful platform for quantum simulation and computation. The rich internal structure of fermionic strontium combined with the second valence electron in alkaline-earth atoms offers exciting new possibilities. However, generating Rydberg states via the metastable $^3P_{0,1,2}$ intermediate states requires an ultraviolet wavelength around 319 nm. Furthermore, exploiting the whole $^3P_{0,1,2}$ manifold requires a tunability of 22 THz, a linewidth of 100 kHz and around 0.25 W of power. This poses a challenge in terms of laser design.

We will describe our progress towards developing such a laser system. Our tunable laser architecture, based on [1], begins with 1.58-μm and 1.07-μm external cavity diode lasers followed by 5-W fiber amplifiers. Sum frequency generation in PPLN generates a 638-nm output, which is then doubled to 319 nm with a resonant BBO cavity. By stabilizing to an atomic-referenced optical transfer cavity we hope to reach linewidths around 100 kHz.

[1] E. M. Bridge et al. Opt. Express 24, 2281 (2016).

Q 39.22 Wed 16:30 Empore Lichthof

Three-Photon Electromagnetically Induced Transparency with Cold Rydberg Atoms — Yagiz Oyun[1], Ozgur Cakir[2], and •Sevilay Sevincli[1] — [1]Izmir Institute of Technology, Department of Photonics, 35430 Urla, Izmir, Turkey — [2]Izmir Institute of Technology, Department of Physics, 35430 Urla, Izmir, Turkey

Electromagnetically induced transparency (EIT) is a quantum coherence phenomenon, in which different excitation paths interfere destructively, canceling out the absorption of the medium for probe laser. Rydberg-EIT media have been used for different applications to gain better understanding of quantum many body interactions since EIT was observed with Rydberg atoms in a two-photon excitation scheme. Dressed state EIT in a four-level scheme was realized experimentally with thermal Cs atoms[1] recently. We investigate three-photon EIT in a cold atomic ensemble by proposing a self-consistent mean-field approach to understand the interaction effects on this system. We also apply the rate equation method to investigate the nonlinear properties of the system. We observed that as the interaction strength increases, transparency weakens as in the two-photon Rydberg-EIT systems, and transparency window broadens and shifts away from the resonance. We acknowledge support from Scientific and Technological Council of Turkey (TUBITAK) Grant No. 117F372.

[1] N. Sibalic, J. M. Kondo, C. S. Adams, K. J. Weatherill, Phys. Rev. A. 94, 033840 (2016).

Q 39.23 Wed 16:30 Empore Lichthof

Ghost Polarization Communication — •Markus Rosskopf, Till Mohr, and Wolfgang Elsässer — Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

The polarization state of polarized light is typically quantified by a Stokes vector on the Poincaré sphere. Completely unpolarized light can be understood as a rapidly altering Stokes vector, with an instantaneous polarization state, that can be characterized by a polarization time which is in the femtosecond regime and can be measured by a photomultiplier detecting two-photon absorption.

Recently, ghost imaging has been extended to new ghost modality domains, in particular ghost spectroscopy and ghost polarimetry (GP) by exploiting correlations in the spectral and polarization domain, respectively. In GP, a hidden polarization state has been successfully recovered by exploiting polarization correlations.

Here, we demonstrate a novel communication scheme between two parties by encoding and camouflaging information in the instantaneous polarization state of unpolarized light emitted by an erbium-doped fiber amplifier. The 2nd order intensity correlation is measured using two-photon absorption interferometry and used to retrieve the transmitted polarization state and thus the message.

The correlation measurements for unpolarized light in our ghost polarization communication setup can be seen in analogy to classical intensity measurements of polarized light using Stokes parameter analysis, thus also offering new insight into the nature of unpolarized light.

Q 39.24 Wed 16:30 Empore Lichthof

Towards fabrication and optimization of LNOI nano-waveguides — •Laura Bollmers, Laura Padberg, Sebastian Lengeling, Christof Eigner, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Lithium niobate on insulator (LNOI) is a material platform of growing interest. Thin-film of lithium niobate currently revolutionizes the old lithium niobate platform since it allows for the miniaturization of devices. Especially the nano-waveguides with its high refractive index difference make them attractive for non-linear processes in integrated optics in general, in particular also for a novel class of quantum optical devices. Due to the novelty of the material, where substantial research occurs since only a few years, the experience with LNOI compared to other materials is still quite limited. This makes LNOI a technological challenging material.
We face the challenge and establish a reliable LNOI technology. On a first step we focused on the fabrication of nano-waveguides. We use a dry etching process with the need of etching masks. Hence, we tested different materials like titanium and photo resist on bare lithium niobate to find the optimal etching masks. We demonstrate that photo resist is the best choice to get smooth waveguide sidewalls. After optimization we transferred the fabrication process to the LNOI platform. We show our recent results of in-house fabricated LNOI nano-waveguides.

Q 39.25 Wed 16:30 Empore Lichthof

Towards a heralded single-photon plug-and-play source — •Christian Kiessler[1], Harald Herrmann[1], Hauke Conradi[2], Moritz Kleinert[2], Raimund Ricken[1], Victor Quiring[1], and Christine Silberhorn[1] — [1]Universität Paderborn, Warburger Str. 100, 33098 Paderborn — [2]Fraunhofer HHI Berlin, Einsteinufer 37, 10587 Berlin

To use quantum technologies and its applications practically, integrated quantum devices must be available. Requirements like stability, affordability, miniaturized design, low loss and fiber compatibility are essential for these devices.
Here, we present our first studies on a polymer embedded LiNbO3 crystal, which is designed as an integrated hybrid heralded single-photon source based on spontaneous parametric down-conversion. Due to the large nonlinearity and the possibility of producing low-loss waveguides, periodically poled Ti:LiNbO3 waveguides are used. The final embedding of the LiNbO3 source into a polymer board, which contains further optical components like waveguides, filters and fiber connections, leads to a practicably usable integrated quantum source. At this point we focus on optimizing the LiNbO3 source to reduce the crystal-polymer interface losses, by studying the mode profile and the interface itself. Furthermore, the exact arrangement of the waveguides and the size of the source are examined.

Q 39.26 Wed 16:30 Empore Lichthof

Towards low-loss electrooptical modulators in $LiNbO_3$ for quantum-optics applications — •Felix vom Bruch, Raimund Ricken, Christof Eigner, Harald Herrmann, and Christine Silberhorn — Universität Paderborn, Warburger Str. 100, 33098 Paderborn

The interest in research on quantum technologies and its applications has been steadily increasing during the last decades and an end to this progress is not yet in sight. Many of the most promising applications are based on using light and its properties for quantum information processing and quantum computing. Recent developments in integrated quantum optics provide multi-functional components, such as converters and modulators, allowing an effective reduction of setup footprints accompanied with active tunability and an increase in performance. The usage of the material $LiNbO_3$ enables one to build a variety of passive and active integrated components, based on its large nonlinearity and the possibility of producing high quality low-loss waveguides. In the single photon regime, for example for frequency conversion or modulation, the importance of low-loss devices increases tremendously. Here, we present our latest activities on obtaining low optical losses in active devices, while optimizing the device architecture in terms of modulation performance. At this point we focus on the geometry of the electrodes relative to the crystal orientation. The built devices are envisaged to combine the advantages of conventional low loss bulk modulators with the fast switching of integrated devices, building a foundation of novel programmable quantum networks.

Q 39.27 Wed 16:30 Empore Lichthof

Post-fabrication correction of $LiNbO_3$ modulators via phase-matching temperature tuning — •Fabian Schlue, Marcello Massaro, Matteo Santandrea, Harald Herrmann, and Christine Silberhorn — Universität Paderborn, Warburger Str. 100, 33098 Paderborn

$LiNbO_3$ is commonly used in nowadays telecommunications, because of its high electrooptic (eo) coefficient and the possibly of low loss waveguides, enabling the production of highly integrated and efficient devices. One class of possible devices, making use of the eo effect, are eo modulators. Here, the required driving voltages scale inverse with the used electrode length. Thus, long devices become advantageous in terms of switching speed. However, when fabricating long devices, it becomes increasingly difficult to obtain high homogeneity due to fabrication imperfections. In order to enhance device performance, the necessity of an effective compensation of those imperfections increase. To investigate this a $LiNbO_3$ chip with four cascaded polarization converters in a single device was characterized.
We achieve the compensation by selectively controlling the temperature of the single converter segments. This configuration allows us to systematically tune the overall output by local adjustments of the phase-matching.
Here, we present our results on controlling the array of segments thermally and electrically to optimize the performance of the built device and prove that local control of devices' properties can be a solution to compensating fabrication imperfections.

Q 39.28 Wed 16:30 Empore Lichthof

A low-cost high-finesse scanning cavity for frequency stabilization of a Ba^+ laser cooling system — •Kai Lok Lam, Daniel Hönig, Fabian Thielemann, Pascal Weckesser, Leon Karpa, and Tobias Schätz — Albert-Ludwigs Universität Freiburg

For most applications in atomic- and molecular physics, lasers at several different wavelenghts are needed. High finesse scanning cavities offer the possibility to transfer the stability of a reference laser to a multitude of other lasers simultaneously. In our setup, we currently aim to use a scanning cavity to transfer the stability of a 650nm laser, that is locked to a Doppler-free spectroscopy of idoine, upon a laser operating at 493nm. These two lasers are used for Doppler-cooling Ba^+-ions for our experiments investigating ultracold collisions with Li or Rb atoms.

In this poster, we present our realization of a home-built high-finesse scanning cavity. We show our setup, including the assembly of the cavity itself as well as the signal processing.

Q 39.29 Wed 16:30 Empore Lichthof

Optomechanical gravity sensing based on cavity QED and phonons in Bose-Einstein condensates — •Benjamin Maass and Dennis Rätzel — Humboldt-Universität zu Berlin Institut für Physik AG Theoretische Optik & Photonik

We theoretically investigate the effect of oscillating gravitational fields on phonons, the collective oscillations of a 1D Bose-Einstein condensate (BEC) that is trapped in an optical cavity. As a result of the coupling between the phonons and the cavity modes, the properties of the gravitational field can in principle be inferred from measurements of the light field alone. The applicability of such optomechanical gravity measurement schemes is evaluated.

Q 39.30 Wed 16:30 Empore Lichthof

Bistability in an optomechanically deformable metasurface — •Carol Bibiana Rojas Hurtado[1], Florian Bruns[2], Johannes Dickmann[1], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt — [2]Technische Universität Braunschweig

We investigate bistability in silicon nanostructured surface used as an optomechanical system in the telecom wavelength range. The surface consists of two layers of subwavelength gratings with high aspect ratio making it compliant to optical forces. Large optical forces result from employing optical modes with high-quality factors, namely quasi-bound states in the continuum. The two interacting forces are computed with Finite Element Analysis: the induced optical forces from an incoming beam that deform the ridges and the opposing elastic restoring force that brings the system to a new equilibrium position. A graphical method is used to find the solutions at a given input intensity, i.e. one solution for one stable state or three solutions for a bistable condition (one unstable and two stable states). With this method, we can also retrieve the hysteresis curve characteristic of bistability. The stable states correspond to two different values of the optical response of the surface, e.g. a high and low reflectivity of the surface. We investigate the possibility to switch up and down between these two stable states, which is promising for an optomechanically controlled switch operating at low input powers in contrast to the much higher intensities needed in common all-optical switches involving nonlinear materials.

Q 39.31 Wed 16:30 Empore Lichthof

Semiclassical rotation dynamics of quantum rigid rotors — •Birthe Papendell[1], Benjamin A. Stickler[2], and Klaus Hornberger[1] — [1]Faculty of Physics, University of Duisburg Essen, Germany — [2]Quantum Optics and Laser Science, Imperial College London, United Kingdom

Recent progress in the optical manipulation [1,2] of levitated aspherical nanoparticles and the prospect of cooling them into their rotranslational ground state [3] open the door for rotational quantum experiments with nanoscale particles [4]. However, calculating the exact rotational quantum dynamics of such objects is numerically intractable due to the high number of involved rotation states. Here, we present semiclassical approximation methods for planar and linear rigid rotors with several thousand occupied angular momentum states revolving in the presence of an external potential.

[1] T. M. Hoang et al., Phys. Rev. Lett. 117, 123604 (2016)
[2] S. Kuhn et al., Nat. Commun. 8, 1670 (2017)
[3] B. A. Stickler et al., Phys. Rev. A 94, 033818 (2016)
[4] B. A. Stickler et al., New. J. Phys. 20, 122001 (2018)

Q 39.32 Wed 16:30 Empore Lichthof

Novel Optomechanical Coupling Mechanisms in nanostructured Metasurfaces — •Florian Feilong Bruns[1], Carol B. Rojas Hurtado[3], Thomas Siefke[2], and Stefanie Kroker[1,3] — [1]Technische Universität Braunschweig, LENA Laboratory for Emerging Nanometrology, Universitätsplatz 1, 38106 Braunschweig, Germany — [2]Friedrich-Schiller-Universität Jena, Abbe Center of Photonics, Institute of applied Physics, Max-Wien-Platz 1, 07743 Jena, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Nanostructured metasurfaces with mechanical degrees of freedom provide a highly flexible platform for optomechanical systems. In this work we investigate bilayer metasurfaces as a platform for dispersive and dissipative coupling in the frame of cavity optomechanics. In the upper layer, the metasurface supports bound states in the continuum, optical modes with high field enhancement. Simultaneously, the bottom layer provides a high mechanical susceptibility thus featuring strong optomechanical coupling. We consider two different aspects: We study metasurfaces for tunable intracavity interactions in multimode systems. Furthermore, we show, that the mechanical loss of mechanical oscillators made of high-purity GaAs can be changed by the light intensity. This effect implies a novel optomechanical coupling mechanism that will enrich the dynamics of experiments in cavity optomechanics.

Q 39.33 Wed 16:30 Empore Lichthof

Approaching the motional ground state of a cold nanomechanical oscillator in a hybrid atom-optomechanical system — •Jakob Butlewski[1], Tobias Wagner[1], Philipp Rohse[1], Cody Friesen[2], Felix Klein[1], Roland Wiesendanger[2], Klaus Sengstock[1], Alexander Schwarz[2], and Christoph Becker[1] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Nanostructure and Solid State Physics, University of Hamburg, Jungiusstraße 11, 20355 Hamburg, Germany

Hybrid quantum systems pose a promising testbed for quantum theory and may further facilitate the implementation of quantum computation and communication protocols. In our pursuit to realize such a hybrid quantum system we have set up a dedicated experiment to couple ultracold ^{87}Rb atoms to a cryogenic nanomechanical oscillator inside a fiber-cavity. In order to approach the motional ground state of the oscillator we apply active feedback cooling, which is based on a continuous position measurement performed by homodyne detection. Here we report on our progress in cooling the oscillator close to the ground state with a final phonon occupancy of $\langle n \rangle = 3.8$. Furthermore we discuss possible limitations for the lowest achievable temperature in our system as well as solutions to overcome these.

Q 39.34 Wed 16:30 Empore Lichthof

Coupling of a cold nanomechanical oscillator to ultracold atoms in a 3D optical lattice — •Felix Klein[1], Jakob Butlewski[1], Tobias Wagner[1], Philipp Rohse[1], Cody Friesen[2], Roland Wiesendanger[2], Klaus Sengstock[1], Alexander Schwarz[2], and Christoph Becker[1] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Nanostructure and Solid State Physics, University of Hamburg, Jungiusstraße 11, 20355 Hamburg, Germany

In recent years hybrid quantum systems became a highly interesting topic as they allow to combine the individual benefits of different quantum systems to overcome the limitations in their respective parts. Therefore, these systems are, among others, promising for future applications in quantum information science. Here we report about coupling a cryogenically cooled nanomechanical trampoline oscillator inside a Fiber Fabry-Pérot Cavity (FFPC) to ultracold atoms in a 3D optical lattice. We characterize the coupling to motional degrees of freedom by loading the atoms into a near-detuned, optical 1D lattice which is formed by back reflection from the oscillator inside the FFPC. Scattering losses due to resonant light are partially compensated by a very deep far-detuned 2D confinement lattice. We observed signatures of resonant coupling in the form of heating the at $\omega_{\mathrm{latt}} = \omega_{\mathrm{m}}$. Coupling the trampoline oscillator to the atoms at varying mode temperature we find clear indications for temperature dependent heating rates.

Q 39.35 Wed 16:30 Empore Lichthof

Levitated opto-mechanics for gravitational wave sensing — •Cristina Matrero Ferrer and Dennis Rätzel — Institut für Physik, Humboldt Universität zu Berlin, Newtonstraße 15, 12489 Berlin

The observation of gravitational waves by the LIGO-Virgo collaboration boosted the interest of the scientific community to the emerging field of gravitational wave astronomy, and also, the interest to find, and hopefully to build, alternative gravitational wave detectors. Interesting alternative options are to use nano-particles levitated in the beamline of an interferometric detector and other advanced opto-mechanical systems. This promises higher precision in different frequency regimes and smaller and cheaper detectors. This work is a theoretical investigation of such opto-mechanical systems as sensors for gravitational waves.

Q 39.36 Wed 16:30 Empore Lichthof

Zerodur based optical benches for microgravity applications — •Jean Pierre Marburger[1], Moritz Mihm[1], Sören Boles[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and the MAIUS and BECCAL team[3,4,5,6,7] — [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

Microgravity environments such as a sounding rocket or a satellite can greatly benefit a number of quantum optics experiments. These experiments often entail a compact and lightweight laser system that can withstand high thermal fluctuations and mechanical stress. To this end, we have developed a technology based on fibre-coupled optical benches made from Zerodur, a glass-ceramic that exhibits a near zero coefficient of thermal expansion, onto which free-space optical components are glued. We have successfully used this toolkit for the creation of a BEC in the scope of the MAIUS-1 sounding rocket mission and will further use it for the upcoming MAIUS-2/3 and the NASA-DLR Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) mission aboard the ISS. For the latter we have adapted our toolkit, making our system even more compact. 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 and 50 WP 1703.

Q 39.37 Wed 16:30 Empore Lichthof

Multi-cell optical memories in warm Cs vapor — •Leon Messner[1,2], Luisa Esguerra Rodriguez[1,2], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany.

The storage of quantum optical pulses in atomic media is considered a key concept in the development of quantum computation and communication techniques. Developing feasable methods for scaling the number of pulses stored, is also an important step in enabling applications such as quantum repeaters [1] and readily available single photon sources [2].

In our experiment we are aiming to map optical excitations to collective atomic states in warm Cs vapor cells with on-demand storage and retrieval. The design is based on an EIT scheme, where a Λ-type atomic system is coupled to free-space control and signal pulses. By deflecting these pulses with acousto-optic modulators prior to entering the atomic media, we can address multiple volumina inside the Cs vapor, thus creating a multi-cell memory [3]. This work is exploring the operational parameters to obtain reproducible optical deflection of the beams for consistent addressing of individual memory cells [4].

[1] Kimble, H., Nature **453**, 1023-1030 (2008)
[2] Nunn, J. et al., PRL **110**, 133601 (2013)
[3] Wolters, J. et al., PRL **119**, 060502 (2017)
[4] Pu, Y. et al., Nat Commun **8**, 15359 (2017)

Q 39.38 Wed 16:30 Empore Lichthof

Quantum Memories suited for Space — •Luisa Esguerra Rodriguez[1,2], Leon Messner[1,2], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany.

Quantum memories are a key element for the realization of quantum repeaters, essential for long-distance quantum communication. Especially for satellite-based quantum networks, alkali metal vapours constitute an excellent storage platform. Moreover, compound quantum systems combining said memories with single photon sources open the path for applications in quantum simulation and computing. The presented project explores a quantum memory implemented in a warm Cesium vapour cell using electromagnetically induced transparency (EIT) on the D1-line, similar to [1]. Light storage, first for attenuated laser pulses and later at the single photon limit, will be investigated. For the latter, single photons from a semiconductor quantum dot source, or a parametric down-conversion source will be used [2]-[4]. Furthermore, noise and efficiency limits of on-demand storage and retrieval will be studied, and optimized. Numerical simulations for optimal storage will be performed.

[1] J. Wolters et al., PRL **119**, 060502 (2017)
[2] J. Wolters et al., arXiv:1908.00590v1 (2019)
[3] A. Ahlrichs, O. Benson, Appl. Phys. Lett. **108,** 021111 (2016)
[4] T. Kroh et al., Sci Rep 9, 13728 (2019)

Q 39.39 Wed 16:30 Empore Lichthof

Ensuring the privacy of random numbers generated by quantum processes — •Johannes Seiler[1], Thomas Strohm[2], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ ST), Universität Ulm, D-89069 Ulm,Germany — [2]Corporate Research, Robert Bosch GmbH, D-71272 Renningen, Germany — [3]Institute of Quantum Technologies, German Aerospace Center (DLR), Söflinger Str. 100, D-89077 Ulm, Germany

An important advantage of a quantum random number generator (QRNG), compared to its classical counterparts, is that quantum mechanics ensures that the generated random numbers are, even in principle, not predictable by an attacker. Unfortunately, real life implementations of QRNGs usually suffer from imperfections that theoretically open the door for an attacker to get at least partial information about the generated numbers. However, if we know how much information an attacker can have maximally gained, postprocessing of the raw data allows to secure the privacy of the random numbers. The task is therefore to obtain an upper bound on this information. We discuss this problem for a realistic QRNG by modeling the random number generator and its environment. As a result, we prove that the information accessible to the attacker crucially depends on the entanglement between the state of the QRNG and its environment. Moreover, we take into account the effects of imperfect measurements. Finally, we provide a scheme that allows us to calculate an upper bound for the accessible information, without any further knowledge of the state.

Q 39.40 Wed 16:30 Empore Lichthof

Efficient single-photon collection for long-distance entanglement of atoms — •Matthias Seubert[1], Robert Garthoff[1], Tim van Leent[1], Kai Redeker[1], Derya Taray[1], Wei Zhang[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany

An essential role in future quantum communication applications, such as quantum repeaters and quantum networks, will be entanglement between quantum memories seperated over large distances. Currently, the entanglement generation rate of single atoms in schemes based on entanglement swapping is limited by the collection efficiency of emitted photons. To overcome this limit, new optics for optimizing the collection efficiency of single photons, emitted by an optically trapped Rb-87 atom was designed. Here we describe the implementation of this new custom designed high-NA microscope objective and its characterization. We obtained an improvement of the photon collection efficiency by a factor of 2.5, which will increase the atom-atom entanglement rate by a factor of 6 with regard to [1]. Furthermore, simulations show that the coupling efficiency of photons into single-mode-fibres can be further increased by 5% using a custom designed fiber collimator. The improved collection efficiency was mendatory to compensate the loss in frequency conversion such that we could demonstrate long distance entaglement between an atom and a photon over 20 km of fiber [2].

[1] W. Rosenfeld, Phys. Rev. Lett. **119**, 010402 (2017)
[2] T. van Leent, arXiv:1909.01006 (2019)

Q 39.41 Wed 16:30 Empore Lichthof

Entanglement conditions for multipartite quantum key distribution — •Giacomo Carrara, Gláucia Murta, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, D-40225 Düsseldorf, Germany

Entanglement is an important resource in quantum cryptography and it is known to be necessary to guarantee security in a bipartite quantum key distribution scenario. It is thus interesting to move to the more complex multipartite scenario, where different classes of entanglement can be defined. In particular we will focus on protocols that utilize a shared multipartite state to generate, each round of the protocol, a common bit of raw key shared among all the parties. Most of the multipartite quantum key distribution protocols of this type proposed so far make use of the Greenberger-Horne- Zeilinger (GHZ) state, or some other genuine multipartite entangled state. Here we ask the question whether genuine multipartite entanglement is necessary to achieve secure multipartite conference key agreement or if biseparable states can also be used in protocols based on multipartite states.

Q 39.42 Wed 16:30 Empore Lichthof

Modification of a Continuous Variable Quantum Authentication Protocol with Physical Unclonable Keys — •Yannick Deller[1], Georgios M. Nikolopoulos[1,2], and Gernot Alber[1] — [1]TU Darmstadt, Darmstadt, Germany — [2]Institute for Electronic Structure & Laser, FORTH, Heraklion, Greece

Entity authentication is an important cryptographic primitive with widespread applications. Entity authentication protocols (EAPs), which rely on physical unclonable keys (PUKs) and involve quantum challenges [1,2], promise a high level of security against classical and quantum adversaries. PUKs are disordered physical objects which are considered to be hard to clone or to simulate. Recently, Nikolopoulos and Diamanti proposed a quantum-optical continuous-variable EAP [2], where the PUK is materialised by a random multiple-scattering medium, while the challenges and the responses are coherent states of light. So far, the security of this protocol has been analysed in the framework of intercept-resend cheating strategies. We discuss the security of the protocol against an emulation attack, which relies on the use of linear quantum-optical chips. It is shown that the protocol of Ref. [2], in its simplest form, is not secure against such a type of attack. Moreover, we discuss possible straightforward modifications of the protocol, so that to prevent this attack, and analyse how the modifications impact the security of the protocol against intercept-resend cheating strategies.

[1] Goorden et al., Optica, Volume 1, 421 (2014)
[2] Nikolopoulos and Diamanti, Sci. Rep., Volume 7, 46047 (2017)

Q 39.43 Wed 16:30 Empore Lichthof

Development of a QKD satellite ground station — •Bastian Hacker[1], Conrad Rössler[1,2], Kevin Günthner[1,2], Ömer Bayraktar[1,2], Jonas Pudelko[1,2], Kevin Jaksch[1,2], Imran Khan[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nuremberg, Staudtstraße 7/B2, 91058 Erlangen, Germany

Quantum Key Distribution (QKD) holds the promise of enabling provable secure communication. In today's efforts based on optical transmission, the challenge is to handle significant transmission losses. Complementary to fiber-based QKD with trusted nodes or quantum repeaters, satellite-based QKD systems [1] for large-distance communication are being developed. To this end, a European quantum satellite will be implemented, capable of secure quantum key exchange with a ground station. We present the project status and highlight some of the technical requirements to operate such a system under real-world conditions.

[1] I. Khan et al., Opt. Photonics News 29(2), 26-33 (2018)

Q 39.44 Wed 16:30 Empore Lichthof

Bounding Secret Key Rates for a Real World QKD Implementation — •Daniel Derr, Alexander Sauer, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt

In general, the secrecy of entanglement based quantum key distribution (QKD) can be guaranteed by checking for the violation of some Bell inequality. The amount of cryptographic key bits, which can be extracted from given measurement results, depends on the strength of this violation. To compute a secret key rate, the chosen protocol and the capabilities of a potential attacker have to be taken into account. We analyze the achievable key rate of a QKD setup based on phase-time coding, which is being developed experimentally at TU Darmstadt. To this end, we take into account the specific properties of that setup, which may give a potential adversary full access over the quantum channel.

Q 39.45 Wed 16:30 Empore Lichthof

Photon Generation by Spontaneous Parametric Down Conversion for Quantum Key Distribution — •Julian Nauth, Alexander Sauer, Erik Fitzke, Gernot Alber, and Thomas Walther — Institut für Angewandte Physik, Technische Universität Darmstadt

We consider a source which generates entangled photons by spontaneous parametric down conversion (SPDC). After passing through a setup, the photons are measured by two parties to generate a secret key via a phase-time coding based quantum key distribution (QKD) protocol. As the requirements for the experimental components are highly demanding in this QKD setup, we aim to characterize the influence of imperfect devices, such that the resulting errors do not have to be attributed to a potential eavesdropper. We simulate the setup by modeling the states of the system as multimode Gaussian states which are transformed by each component of the setup. With this, SPDC and subsequent frequency- and polarization-dependent effects are modeled. The simulation yields the correlations of detection events for the parties at different times. We compare our calculations to experimental results and analyze the influence of different device imperfections on the correlations.

Q 39.46 Wed 16:30 Empore Lichthof

Towards quantum teleportation in space and frequency using a comb of squeezed vacuum — •Dennis Wilken[1,2,3], Jonas Junker[1,2,3], and Michèle Heurs[1,2,3,4] — [1]Leibniz Universität Hannover, Institut für Gravitationsphysik, Deutschland — [2]Max Planck Institut für Gravitationsphysik, Deutschland — [3]QuantumFrontiers — [4]PhoenixD

Sources of squeezed vacuum are now routinely implemented in gravitational wave detectors. These so-called "squeezers" are based on a parametric down-conversion process generating pairs of entangled photons at frequencies $\pm\Omega$ with respect to the laser frequency. We intend to use this entanglement by frequency-dependently separating these photons using an unbalanced Mach-Zehnder interferometer or detuned cavities. We are designing different experiments, such as a measurement-induced entanglement and entanglement swapping, to demonstrate quantum teleportation in space and frequency. This could enable frequency multiplexing in continuous variable quantum communication.

We have set up an optical parametric oscillator cavity that runs below threshold to generate squeezed states of vacuum. It has a comparably high roundtrip length of 1.5 m to generate a squeezing comb with a "teeth separation" of only 200 MHz. We were able to generate and stably lock 9 dB of squeezing. We have developed a low-noise and high-speed homodyne-detector that provides more than 10 dB of clearance between shot noise and electronic noise up to 3 GHz. We will present the current status of the experiment and the next steps.

Q 39.47 Wed 16:30 Empore Lichthof

Microwave antenna design for fiber-based microcavities — •Jonas Grammel, Maximilian Pallmann, and David Hunger — Physikalisches Institut (PHI), Karlsruher Institut für Technologie, Wolfgang-Gaede-Str.1, 76131 Karlsruhe, Germany

The realization of a quantum repeater is a central subject of current research in the field of optical quantum technologies. One promising platform to implement an efficient spin-photon interface - which is the basic building block of a quantum repeater - is based on NV centers in diamond coupled to tunable, fiber-based microcavities [1,2,3]. Asides to excellent optical cavity-emitter coupling and coherent optical control, one also requires direct control of the spin degree of freedom via microwave radiation [4]. Therefore, we develop a microscopic microwave antenna which is directly integrated in the fiber cavity assembly in a way that isolates the thermal impact of the antenna from the diamond sample [5]. We will describe the current state of the efforts to use this antenna to measure optically detected magnetic resonance and drive arbitrary pulse sequences.

[1] D. Hunger et al., New J. Phys. 12, 065038 (2010) [2] H. Kaupp et al., Phys. Rev. Appl. 6, 054010 (2016) [3] D. Riedel et al., Phys. Rev. X 7, 031040 (2017) [4] S. Bogdanovic et al., APL Photonics 2, 126101 (2017) [5] I. Fedotov et al., Sci Rep 4, 5362 (2015)

Q 39.48 Wed 16:30 Empore Lichthof

Entanglement for non-adaptive measurement-based quantum computation — •Bülent Demirel[1], Weikai Weng[1], Christopher Thalacker[1], Akshey Kumar[1], Matty Hoban[2], and Stefanie Barz[1] — [1]Universität Stuttgart — [2]Goldsmiths, University of London

Multipartite entangled states are useful for applications such as quantum networking and computing but also enable intriguing experiments on fundamental questions of quantum physics. Today*s quantum technologies are based on the properties of large ensembles of particles. We show the generation of 4-photon entanglement and test inequalities that correspond to computational games for computing a Boolean function of three bits distributed across four parties - this is all in the non-adaptive measurement-based quantum computation (MBQC) model.*Our inequalities compare quantum with classical where we don*t allow any communication for the classical model or where some limited communication, for a circuit of depth 1, is allowed. We experimentally verify a violation of the inequalities as this demonstrates that quantum can outperform a classical communication circuit.

Q 39.49 Wed 16:30 Empore Lichthof

Building the necessary setup infrastructure for spin-photon entanglement and quantum repeaters with colour centers in silicon carbide. — •Izel Gediz, Naoya Morioka, Matthias Niethammer, Charles Babin, Di Liu, Erik Hesselmeier, Roland Nagy, Durga Dasari, Florian Kaiser, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart and IQST, Stuttgart, Germany

Concerning the scalability of quantum information and networking applications, colour centers in silicon carbide (SiC) have proven to be promising candidates. The successful implementation of a quantum repeater requires a high-quality spin-photon entanglement interface.Our recent work on silicon vacancy centres in SiC showed spin-controlled indistinguishable and distinguishable photon emission through Hong-Ou-Mandel interference experiments. Here, I will show our current work on developing the necessary setup infrastructure for realising spin-photon entanglement generation. To ensure transform limited photon emission over long times, a high-finesse filter cavity was developed. A cross-polarised sub-nanosecond-pulsed excitation-emission setup was implemented to efficiently reject laser noise by more than 7 orders of magnitude. Finally, an unbalanced fibre interferometer was set up to analyse photonic time-bin quantum states. For all systems, active monitoring and stabilisation feedback is provided through a Python computer code. Our successful setup implementation paves the way for future spin-photon entanglement experiments with colour centres in an industrial semiconductor platform.

Q 39.50 Wed 16:30 Empore Lichthof

Certified Randomness from Bell's Theorem and Dimension Witness — •Xing Chen[1], Ilja Gerhardt[1], Jörg Wrachtrup[1,2], Robert Garthoff[3,4], Kai Redeker[3,4], Wenjamin Rosenfeld[3,4], and Harald Weinfurter[3,4] — [1]3. Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology IQST, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, D-80799 München, Germany — [4]Max-Planck Institut für Quantenoptik, D-85748 Garching, Germany

Device-independent (DI) randomness can be certified from experimental data which violates the CHSH inequality. The certification procedure in previous studies cannot fully extract the DI randomness by an analytical formula. We solve this problem by developing an analytical upper bound for the joint outcome probability $p(ab|xy)$. Compared to the formula in S. Pironio et al. [Nature (London) 464,1021(2010)], the lower the violation S value is, the relative more DI randomness can be certified by our analytical bound. Under less secure semi-device-independent (SDI) conditions, which use dimension witnesses [1], substantial more randomness can be extracted than in the device-independent cases. We furthermore apply our models for the loop-hole free Bell test experiment [2], the results show that nearly half of the experimental events can be certified as SDI randomness.

[1] J. Bowles,et al.,PRL.112.14(2014):140407.
[2] W. Rosenfeld,et al.,PRL.119.1(2017):010402.

Q 39.51 Wed 16:30 Empore Lichthof

Certified Randomness from Bell's Theorem and Dimension Witness — •Xing Chen[1], Ilja Gerhardt[1], Jörg Wrachtrup[1,2], Robert Garthoff[3,4], Kai Redeker[3,4], Wenjamin Rosenfeld[3,4], and Harald Weinfurter[3,4] — [1]3. Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology IQST, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, D-80799 München, Germany — [4]Max-Planck Institut für Quantenoptik, D-85748 Garching, Germany

Device-independent (DI) randomness can be certified from experimental data which violates the CHSH inequality. The certification procedure in previous studies cannot fully extract the DI randomness by an analytical formula. We solve this problem by developing an analytical upper bound for the joint outcome probability $p(ab|xy)$. Compared to the formula in S. Pironio *et al.* [Nature (London) 464,1021(2010)], the lower the violation S value is, the relative more DI randomness can be certified by our analytical bound. Under less secure semi-device-independent (SDI) conditions, which use dimension witnesses [1], substantial more randomness can be extracted than in the device-independent cases. We furthermore apply our models for the loop-hole free Bell test experiment [2], the results show that nearly half of the experimental events can be certified as SDI randomness.

[1] J. Bowles, *et al.*, PRL.112.14 (2014):140407.
[2] W. Rosenfeld, *et al.*, PRL.119.1 (2017):010402.

Q 39.52 Wed 16:30 Empore Lichthof

Monte Carlo simulations for determining the volume ratio separable to entangled states in a two-qubit system — •Héctor José Moreno[1], Józef Zsolt Bernád[1,2], and Gernot Alber[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — [2]Department of Physics, University of Malta, Msida MSD 2080, Malta

In this work, we investigate the question of how many separable states are in the set of all quantum states. We focus on a two-qubit composite system and its Fano type of parametrization. The number of free parameters is 15 and due to the chosen parametrization, we are able to characterize general self-adjoint matrices with trace one and eigenvalues between minus one and one. Thus, the first task is to find all positive matrices, i.e., the density matrices, which can be realized with the help of the Newton identities. These identities lead to three inequalities and these analytical results are investigated with the help of Monte Carlo simulations. Then, the separability of the states is determined using the Peres-Horodecki criterion. While many previous approaches have considered this question, here we try a different numerical and analytical approach for estimating the volume ratio of separable to entangled states. Our combined analytical and numerical approaches can also be extended to a qubit- qutrit system, where the Peres-Horodecki criterion still holds.

Q 39.53 Wed 16:30 Empore Lichthof

Test of a time-bin entanglement-based QKD system in a commercial optical link — •Jakob Kaltwasser, Erik Fitzke, Oleg Nikiforov, Maximilian Tippmann, and Thomas Walther — AG Laser und Quantenoptik, Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Quantum Key Distribution has significant relevance in further development of cryptographic data exchange and key distribution systems. It offers new aspects of enhancement in security for key distribution compared to classical protocols. We are working on a time-bin entanglement-based system for quantum key distribution which is developed and tested in a commercial telecommunication environment. This non-laboratory environment has challenging aspects especially with respect to a portable and compact system as well as a high instability of temperature and noise background and its effects on the system. Consequently we developed a compact optical-fiber-based system for the photon-pair source. In this contribution we discuss the recent progress of our experiment and present our latest results.

Q 39.54 Wed 16:30 Empore Lichthof

A quantum network node with crossed fiber cavities — •Gianvito Chiarella[1], Manuel Brekenfeld[1], Dominik Niemietz[1], Pau Farrera[1], Joseph D. Christesen[1,2], and Gerhard Rempe[1] — [1]MPQ, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]NIST, Boulder, Colorado 80305, USA

Single atoms embedded in optical cavities have been proven to be a clean and fruitful experimental platform for the study of quantum information processing. In recent years, limits on the reduction of the cavity mode volume imposed by traditional manufacturing processes of the cavity mirrors have been overcome with the introduction of Fabry-Perot fiber cavites (FFPCs) [1]. Beside small mode volumes and larger coupling rates, FFPCs also allow for new geometries due to their smaller dimensions that enables the increase of the number of independent cavity modes the atom can couple to. We have set up a new experiment with single neutral atoms trapped at the center of two crossed FFPCs. Exploiting the possibilities provided by the new system, we have realized a quantum network node that couples to two spatially and spectrally distinct quantum channels. The node functions as a passive, heralded and high-fidelity quantum memory that requires neither amplitude- and phase-critical control fields [2] nor error-prone feedback loops [3] and is thus excellently suited for the realization of large-scale quantum networks and quantum repeaters.

[1] Hunger et al., New J. Phys. **12**, 065038 (2010)
[2] Specht et al., Nature **473**, 190 (2011)
[3] Kalb et al., Phys. Rev. Lett. **114**, 220501 (2015)

Q 39.55 Wed 16:30 Empore Lichthof

Quantum Memories based on Adiabatic Transfer and Beyond — •Tom Schmit, Luigi Giannelli, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

Quantum memories are the storage units of a quantum network [1]. The transfer of the qubit state to the memory can be accomplished by different types of protocols. Typically, protocols based on adiabatic dynamics are preferrable due to their robustness against moderate fluctuations of experimental parameters, on the other hand they require long-transfer times. In this work we analyse theoretically the efficiency of adiabatic storage of single photons [2] in quantum memories based on (i) a single atom inside an optical resonator and (ii) a solid-state medium. We discuss the efficiency of protocols based on adiabatic dynamics [3,4] when applied in the non-adiabatic regime. We finally extend these protocols by including pulses determined via optimal control theory and analyse their efficiency.

[1] H. J. Kimble, Nature **453**, 1023 (2008).
[2] N. Sangouard and H. Zbinden, Jour. of Mod. Opt., **59:17**, 1458-1464 (2012).
[3] M. Fleischhauer, and M. D. Lukin, Phys. Rev. A, **65**, 022314 (2002).
[4] A. V. Gorshkov, A. André, M. D. Lukin, and A. S. Sørensen, Phys. Rev. A, **76**, 033804 (2007).

Q 39.56 Wed 16:30 Empore Lichthof

A Versatile High-Speed Continuous-Variable Quantum Communication System — Imran Khan[1,2], •Stefan Richter[1,2], Kevin Jaksch[1,2], Kevin Guenthner[1,2], Ömer Bayraktar[1,2], Emanuel Eichhammer[1,2], Bastian Hacker[1,2], Birgit Stiller[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Over the last years, the quantum information processing group at MPL has developed a fiber-based continuous-variable quantum communication system for deployment alongside and compatible with existing telecom infrastructure. In this work, we present our technological advancements as well as the role of this fiber-based quantum communication system within national and EU quantum flagship projects. The projects covered are: HQS (BMBF), QuNET (BMBF), CiViQ (EU Quantum Flagship) and the European quantum key distribution testbed OPENQKD (EU H2020).

Q 39.57 Wed 16:30 Empore Lichthof

Magnetic interactions in nonequilibrium atom-surface dispersion forces — •Simon Hermann[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 Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

Driving a microscopic object above a planar medium induces a force opposing the direction of motion even if both the object and the material are non-magnetic and electrically neutral. The interaction stems from the fluctuations within the microscopic object and the medium and occurs even if the temperature goes to zero, rendering the effect a purely quantum phenomenon. This fluctuation-induced interaction heavily relies on long-time correlations making it an excellent example of a non-Markovian nonequilibrium phenomenon [1]. Due to the mathematical complexity of the problem, most of the earlier descriptions focused on the electric contribution to the interaction. Here, we present a more complete treatment that also takes into account the contribution arising from the nonequilibrium magnetic fluctuations of the system.

[1] F. Intravaia, R. O. Behunin, C. Henkel, K. Busch and D.A.R. Dalvit
Non-Markovianity in atom-surface dispersion forces Phys. Rev. A **94** 042114 (2016).

Q 39.58 Wed 16:30 Empore Lichthof

Probing the Quantum Vacuum with High-Intensity Laser Fields — Ricardo R.Q.P.T. Oude Weernink[1,2], •Leonhard Klar[1,2], Felix Karbstein[1,2], and Holger Gies[1,2] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany

From the perspective of quantum field theory vacuum is not the absence of everything but characterized by the omnipresence of quantum vacuum fluctuations. In contrast to classical vacuum it is described by virtual particle-antiparticle pairs being created and annihilated on extremely short time and length scales. The theory of quantum electrodynamics (QED) predicts non-linear effective interactions between electromagnetic fields mediated by such vacuum fluctuations. These effects however are yet to be measured directly.

One example of QED vacuum non-linearity is the process of photon-photon scattering. In order to make this process experimentally accessible we suggest two different approaches. The first collides several tightly focused fundamental Gaussian laser beams. Using frequency doubling and a special geometry we generate a narrow high-intensity scattering center allowing us to obtain signal photons discernible from the background of the driving laser beams. In the second approach, we limit ourselves to two counter-propagating pulses. This time however both beams are considered to be arbitrary Hermite-Gaussian modes. This results in interesting field configurations which are examined for their potential to induce signal photons distinguishable from the background with finite impact parameter.

Q 39.59 Wed 16:30 Empore Lichthof

State transfer from a single photon to a quantum emitter and quantum cloning — •Marvin Gajewski, Thorsten Haase, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, Deutschland

Achieving optimal quantum state transfer from a single photon to a quantum emitter is a highly desired task in quantum information processing. This enables conversion from flying into stationary qubits and enhances quantum computation and communication, in particular scalable communication networks. A scheme achieving this task was presented in [1]. It enables an almost perfect transfer of the information stored in the polarization degrees of freedom of a single photon onto a suitable level scheme of a single quantum emitter by exploiting the dissipation induced by spontaneous emission of photons. It has been shown that under certain assumptions, such as orthogonality of the involved photonic reservoirs, a particular balancing of the relevant photonic spontaneous decay rates is necessary.

In this contribution we generalize these investigations by dropping some of these previous assumptions, such as the orthogonality of the coupling and background modes involved. Within this more general scenario it is explored to which extent imperfect quantum cloning is possible due to information leakage into the state of the spontaneously emitted photon.

Q 39.60 Wed 16:30 Empore Lichthof

Numerical calculation of Casimir interactions in complex geometries — •Bettina Beverungen[1], Philip Kristensen[1], Francesco Intravaia[1], and Kurt Busch[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

The Casimir effect is responsible for a force between nonmagnetic, electrically neutral objects arising from the quantum fluctuations of the electromagnetic field. This interaction has received increasing attention from both theoretical and experimental side, in particular for its relevance in the design of small-scale devices such as nano- or micro electro-mechanical systems and atom-chips. To fully explore the space of possible designs, it is imperative to develop methods to evaluate Casimir forces for non-trivial geometries and materials allowing for high flexibility and precision. Here, we discuss a time-domain finite-element-based numerical scheme employing the discontinuous Galerkin time-domain (DGTD) method. This calculation method enables high-accuracy evaluation of Casimir- and Casimir-Polder forces in complex geometries and for a broad class of material models.

Q 39.61 Wed 16:30 Empore Lichthof

Interplay between collective Lamb shift and hyperfine splitting in resonant x-ray scattering — •Petar Andrejić, Xiangjin Kong, and Adriana Pálffy — Max Planck Institute for Nuclear Physics, 69117 Heidelberg,Germany

In an ensemble of identical atoms, cooperative effects like superradiance may alter the decay rates and the transition energies may be shifted from the single-atom value by the so-called collective Lamb shift. While such effects in ensembles of two-level systems are well understood, realistic multi-level systems are more difficult to handle. Mössbauer nuclei in x-ray thin-film cavities are a clean quantum optical system in which the collective Lamb shift has been observed [1].

Here, we present a quantitative study of ensembles of ^{57}Fe nuclei which considers for the first time the action of both an external magnetic field and an intrinsic quadrupole splitting. We show that a collective contribution to the level shifts appears that can amount to sizable deviations from the single-atom hyperfine splitting due to the interplay with the collective Lamb shift. We discuss possible experimental evidence of deviations in the radiation spectrum compared to the case of single-nucleus magnetic-field-induced splitting [2].

[1] R. Röhlsberger *et al.*, Science 328, 1248 (2010).
[2] X. Kong and A. Pálffy, Phys. Rev. A 96, 033819 (2017).

Q 40: Precision Measurements and Metrology (Atom Interferometry)

Time: Thursday 11:00–13:00 Location: a310

Group Report Q 40.1 Thu 11:00 a310

Very Long Baseline Atom Interferometry: vision and challenges — •Etienne Wodey[1], Christian Meiners[1], Dorothee Tell[1], Robert J. Rengelink[1], Manuel Schilling[2], Klaus Zipfel[1], Wolfgang Ertmer[1], Christian Schubert[1], Ludger Timmen[2], Jürgen Müller[2], Dennis Schlippert[1], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Leibniz Universität Hannover, Institut für Erdmessung

Atom interferometers are powerful tools to perform precision measurements and search for new physics. New applications, including the detection of gravitational waves and exotic matter searches, nevertheless require significant upgrades to the sources of ultracold atoms with enhanced atom numbers and repetition rates on long baselines to achieve low instabilities. In addition, improved control over wavepacket dynamics and the homogeneity of the interferometer's environment are key to reduce instrumental biases.

We report on the development of the Very Long Baseline Atom Interferometry (VLBAI) facility, a 10 m-baseline device located at the newly founded Hannover Institute of Technology (HITec). Based on our work on large scale magnetic shielding and gravitational environment mapping as well as on vibration isolation and high-flux atomic sources, we review recent advances towards effective long baseline matterwave inertial sensors, and discuss methods and challenges for the next generation ultra long baseline atom interferometers.

We acknowledge support by the DFG (Großgeräte), the CRCs 1128 "geo-Q" and 1227 "DQ-mat", and the EXC 2123 "QuantumFrontiers".

Q 40.2 Thu 11:30 a310

International Space Station-based Cold Atom Lab: status of first flight investigations — •Naceur Gaaloul[1,5], Annie Pichery[1,5], Waldemar Herr[1,5], Holger Ahlers[1,5], Christian Schubert[1,5], Wolfgang Ertmer[1,5], Ernst. M. Rasel[1,5], Matthias Meister[2,5], Patrick Boegel[2,5], Wolfgang P. Schleich[2,5], Robert Thompson[3], Jason Williams[3], Nicholas P. Bigelow[4,5], and the CUAS Consortium[5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Quantenphysik, Universität Ulm — [3]Jet Propulsion Laboratory, California Institute of Technology — [4]the University of Rochester — [5]The Consortium for Ultracold Atoms in Space

Space offers a unique low-noise, low-gravity environment necessary for deploying competitive quantum sensors covering a wide spectrum of applications ranging from time and frequency transfer to Earth observation and the exploration of fundamental laws of physics. In this contribution, we report about the CUAS consortium activities within the NASA Cold Atom Lab stationed aboard the International Space Station. It consists of a multi-user Bose-Einstein Condensate facility continuously operating in-orbit. The outcome of a year of operations is presented and their significance for follow-up missions testing general relativity, quantum mechanics or cosmology predictions is highlighted.

We acknowledge financial support from DLR (Grant No. 50WM1861/2), the "Niedersächsisches Vorab" (QUANOMET, new DLR-SI Institute) and NASA (CUAS RSAs including 1585910).

Q 40.3 Thu 11:45 a310

Atom interferometry in the transportable Quantum Gravimeter QG-1 — •Nina Heine[1], Jannik Wesche[1], Sven Abend[1], Waldemar Herr[1], Jürgen Müller[2], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The transportable Quantum Gravimeter QG-1 will perform absolute measurements of the local gravitaional accelaration with an unrivalled uncertainty below 3 nm/s^2 by utilising collimated atomic ensembles for atom interferometry in a compact setup. To achieve this performance, leading order error sources, predominantly stemming from the horizontal velocity of the interrogated atoms, need to be minimised. This talk elaborates on the design and implementation of the interferometry setup into the atom chip based experimental system. The center of mass motion and the velocity spread of the atomic cloud, as well as their impact on the beam splitting process are evaluated to develop a comprehensive understanding of their contribution to the uncertainty.

We acknowledge financial support from "Niedersächsisches Vorab" through "Förderung von Wissenschaft und Technik in Forschung und Lehre" for the initial funding of research in the new DLR-SI Institute and by the Deutsche Forschungsgemeinschaft (DFG) in the project

A01 of the SFB 1128 geo-Q and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 40.4 Thu 12:00 a310

MAIUS-B: Development and test of the scientific payload — •Baptist Piest, Jonas Böhm, Maike Lachmann, Ernst Rasel, and The QUANTUS team — Institut für Quantenoptik, LU Hannover

Quantum tests of the Einstein equivalence principle (EEP) promise to outreach the accuracy of classical tests based on macroscopic test masses in the course of the next decade. Additionally, they offer to probe quantum aspects of the EEP which are inherently inaccessible for classical tests. Current limitations of ground-based tests using light-pulse matter-wave interferometry are mainly given by the maximum pulse separation time T and the terrestrial environment. A promising approach to overcome this limitation is to perform the experiments in extended free fall, e.g. on a satellite. In 2017, the sounding rocket experiment MAIUS-1 succeeded in generating the first BECs in space using Rb-87 atoms and demonstrated further key methods needed for an EEP test in space. The missions MAIUS-2 and -3 aim to demonstrate BEC-borne dual-species matter wave interferometry with K-41 and Rb-87. This talk shows the current experimental status with a focus on the creation of ultracold mixtures and the interferometry setup. 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 40.5 Thu 12:15 a310

Simulations of Integrated Laser-Guided Atom Interferometers — •Matthew Glaysher, Florian Fitzek, Sina Loriani, Ernst Maria Rasel, and Naceur Gaaloul — Leibniz Universität Hannover, Institute of Quantum Optics, Germany

Atom interferometry provides a highly accurate measurement tool, its applications ranging from inertial sensing and navigation to tests of fundamental physics. High precision interferometry is achieved either by Large Momentum Transfer or long interrogation times. Whereas the more common light pulse interferometer schemes can produce the necessary momentum transfer, guided interferometers can achieve long interrogation times. For guided ensembles it is essential to understand the internal interactions, as well as the inherent systematics they cause, to realize a phase-sensitive interferometer. For this purpose we compute the dynamics of Bose-Einstein Condensates (BECs) by numerically solving the Gross-Pitaevskii-Equation. We specifically investigate beam-splitting mechanisms and the phase evolution of BECs in a guided system, realized by dynamically shaped cavity modes or painted potentials.
The presented work is supported by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL)

Q 40.6 Thu 12:30 a310

Universal atom interferometry simulator for precision sensing — •Florian Fitzek[1,2], Jan-Niclas Siemss[1,2], Holger Ahlers[2], Ernst M. Rasel[2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institut für Theoretische Physik, LU Hannover — [2]Institut für Quantenoptik, LU Hannover

Quantum sensors based on light-pulse atom interferometers allow for high-precision measurements of inertial and electromagnetic forces, accurate determination of fundamental constants as the fine structure constant α or to test foundational laws of modern physics as the equivalence principle. The full potential, i.e. sensitivity of these schemes unfolds when large interrogation times or macroscopic arm separation could be implemented. Both directions, however, imply a substantial deviation from an ideal interaction of light with atomic systems. Indeed, real-life complications as finite pulse areas and fidelities, momentum width broadening of the cold clouds, atomic interactions or light fields distortions limit the measurements but more dramatically hinder a reasonable systematics study. This is mainly due to the limited number of analytical cases and to the realistic numerical calculations being intractable.

In this study, we contribute to the precise formulation and simulation of the aforementioned effects by employing a position space solver of the Gross-Pitaevskii equation. We specifically target problems connected to gravity sensing as well as the dephasing in trapped atom interferometers. The work is supported by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 40.7 Thu 12:45 a310

Beamsplitters and sensitivity to relativistic effects in atom-interferometry — •Alexander Friedrich[1], Butrint Pacolli[1], Fabio Di Pumpo[1], Enno Giese[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, D-89077 Ulm, Germany

Recently, quantum-clock interferometry [1] has been suggested to investigate relativistic effects on the center-of-mass motion in superpositions of internal states. These proposals combine high-precision quantum metrological techniques with studies of the fundamental interconnections between relativity and quantum mechanics. Complementary to tests of relativity with atomic clocks, quantum-clock interferometry allows one to test these effects with a single but delocalized quantum object. However, the sensitivity with respect to relativistic effects [1,2] depends crucially on the geometry and the specific details of the involved beamsplitting processes. In our contribution we investigate, elaborate and clarify the link between typical beamsplitters used in the proposed schemes and the sensitivity to relativistic effects.
The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956.

[1] A. Roura, arXiv 1810.06744, (2018)
[2] S. Loriani, A. Friedrich et al., Sci. Adv. **5** (10), eaax8966 (2019)

Q 41: Quantum Information (Quantum Communication and Quantum Repeater) I

Time: Thursday 11:00–13:00 Location: e001

Group Report Q 41.1 Thu 11:00 e001

Photonic qubit memories for quantum networks — •Olivier Morin, Stefan Langenfeld, Matthias Körber, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching

The storage of qubits is an extremely important capability for the implementation of numerous protocols in quantum information technology. In the context of quantum networks the qubits are transported from one node to another via the exchange of photonic states. Here, we will report on our progress on photonic memories using single 87Rb atoms in a high finesse cavity.

First, one important figure of merit is the storage time. By using different atomic states we have extended the coherence time beyond 100ms [1]. The second important figure of merit is the efficiency of the memory. This latter does not only rely on minimizing optical losses but also on the accurate control of the temporal shape of the photons that carry the qubits [2]. Last but not least, in order to be used in advanced applications like quantum repeaters, pairs of memories that can interact with each other are desired. We have recently shown that we can have two individual atoms in the same optical cavity mode and use them as Random Access Quantum Memories for more than 10 qubits with high fidelity and low cross talk [3].

[1] M. Körber et al., Nat. Photonics 12, 18 (2018).
[2] O. Morin et al., Phys. Rev. Lett. 123, 133602 (2019).
[3] S. Langenfeld et al., in preparation (2019).

Q 41.2 Thu 11:30 e001

Single-Photon Distillation with an Atom-Cavity System — •Stephan Welte[1], Severin Daiss[1], Lukas Hartung[1], Emanuele Distante[1], Bastian Hacker[1,2], Lin Li[1,3], and Gerhard Rempe[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching — [2]Present address: Max-Planck-Institut für die Physik des Lichts, Staudtstr. 2, 91058 Erlangen — [3]Present address: School of Physics, Huazhong University of Science and Technology, Wuhan, China

Custom-shaped single photons are an indispensable tool for many applications in quantum communication. We distill them out of incoming weak optical pulses that are reflected from and entangled with an atom-cavity system [1]. A suitable measurement on the atom is used to herald the suppression of undesired photon-number contributions. Additionally, the temporal mode profile of the generated photons can be tailored. Out of vacuum-dominated coherent pulses, we distill single photons with a fidelity of 66%. Applying our protocol to state-of-the-art fiber cavities [2] would allow one to reach single-photon fidelities of up to 96%.

[1] S. Daiss, S. Welte, B. Hacker, L. Li, G. Rempe, PRL **122**, 133603 (2019)
[2] M. Uphoff, M. Brekenfeld, G. Rempe, S. Ritter, New J. Phys. **17**, 013053 (2015)

Q 41.3 Thu 11:45 e001

Development of Single Photon Quantum Frequency Conversion for Quantum Computing Networks — •Marcel Hohn and Simon Stellmer — Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn

In recent years, numerous physical implementations of qubit systems, ranging from trapped ions to solid state quantum dots, have been realized. For reliable long-distance transport of quantum information between quantum systems, the usage of single photons as so-called flying qubits is the most convenient choice. The development of a hybrid quantum network permits to incorporate the benefits of different systems. This requires a means to convert the frequencies of these single photons between the operation frequencies of the respective platforms while preserving the quantum correlations, which is accomplished by quantum frequency conversion (QFC) via sum- and difference frequency generation (SFG/DFG) in a nonlinear material. Here we report on the development of a quantum frequency conversion setup between the Yb^+ dipole transition at 369.5 nm and InGaAs quantum dots at about 850 nm using a waveguide in periodically poled potassium titanyl phosphate (PPKTP).

Q 41.4 Thu 12:00 e001

Spin-controlled indistinguishable and distinguishable photon emission from colour centres in silicon carbide — •Florian Kaiser, Naoya Morioka, Roland Nagy, Izel Gediz, Erik Hesselmeier, Charles Babin, Matthias Niethammer, Roman Kolesov, Durga Dasari, Rainer Stöhr, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart and IQST, Stuttgart, Germany

The silicon carbide (SiC) platform has recently shown extremely promising advancements for scalable quantum information applications [1]. To foster the platform's full potential, entanglement generation is crucial, which may be efficiently mediated through photonic interference [2].

Here, we show that the silicon vacancy (VSi) centre in SiC provides the necessary spin-optical interface. First, we show high quality Hong-Ou-Mandel interference experiments. Then, we show how we control the photonic interference pattern via coherent electron spin control.

Our results clearly demonstrate that VSi centres in SiC are capable of generating photon-mediated spin-spin entanglement. This crucial step demonstrates the potential of the system for realising large-scale quantum networks.

[1] R. Nagy et al., Nat. Commun. 10, 1954 (2019)
[2] F. Rozpedek et al., Phys. Rev. A 99, 052330 (2019)

Q 41.5 Thu 12:15 e001

Photon entanglement distribution using a single trapped ion as quantum memory — •Martin Steinel, Matthias Kreis, Jan Arenskötter, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The generation of remote entanglement at long distances is a fundamental component in quantum networks. To achieve long distance entanglement through a fiber network, quantum repeaters [1] operating on quantum memories (QM) must be employed. Focusing on trapped ions as QMs [2-4] in a quantum repeater cell [5] we compare several protocols quantitatively with numerical simulations in terms of qubit rate and background contributions. Implemented as a finite state machine, we simulate an emission protocol for a single qubit QM consecutively emitting two entangled photons, and an absorption protocol. In the latter, two entangled photon pairs are generated by SPDC and one partner of each pair is absorbed consecutively by the QM. The necessary Bell state measurement is performed by projection of heralds of absorption and the final atomic state, that allows to distinguish all four Bell states. The simulations are compared with two qubit QM schemes in terms of efficiencies and experimental parameters of our existing setup and possible future developments.

[1] H.-J. Briegel et al., Phys. Rev. Lett. **81**, 5932 (1998)
[2] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)
[3] C. Kurz et al., Phys. Rev. A **93**, 062348 (2016)
[4] M. Bock et al., Nat. Commun. **9**, 1998 (2018)
[5] C. Panayi et al., New J. Phys. **16**, 043005 (2014)

Q 41.6 Thu 12:30 e001

Integrated photonics for quantum communications in space — Ömer Bayraktar[1], •Jonas Pudelko[1], Winfried Boxleitner[2], Christoph Pacher[2], Gerd Leuchs[1], and Christoph Marquardt[1] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Austrian Institute of Technology, Vienna, Austria

The limited range of quantum key distribution (QKD) in fiber based systems led to several projects aiming for the development of a satellite based QKD infrastructure. Photonic integrated circuits (PICs) are a convenient way to implement all necessary optical functions, while meeting the stringent demands on size, weight and power in satellite missions.

In this work, we present our payload designed for the demonstration of integrated quantum communication technology in space and its first tests. It is based on two Indium-Phosphide PICs implementing a source for modulated weak coherent states as well as a quantum random number generator (QRNG) based on homodyne measurements of the quantum mechanical vacuum state. The whole system is implemented on a 10 cm x 10 cm PCB including all electronics and processing units, while also being compatible to the CubeSat standard.

These developments will be tested as part of the CubeSat mission QUBE.

Q 41.7 Thu 12:45 e001

Orchestrating parametric down conversion temporal modes — •Jano Gil Lopez, Vahid Ansari, Benjamin Brecht, and Christine Silberhorn — Paderborn Universität, Warburgerstr. 100 33098 Paderborn

Photon temporal modes (TM) are a powerful tool for quantum information science (QIS). They span a high-dimensional Hilbert space, which is compatible with spatially single-mode fibres. QIS can benefit from such high-dimensional spaces; they provide an increase in the security of quantum key distribution as well as in the information capacity of photons, while allowing for the utilisation of off-the-shelf telecommunication components. These advantages can be improved further, if the distribution of TMs is tailored to be equally distributed over a controlled number of effective modes, thereby producing maximally entangled states. We implement an engineered parametric down conversion source of controlled TM bi-photon states with equally-weighted mode distribution. The states are characterised through joint spectral intensity and second order correlation measurements. We demonstrate the generation of maximally entangled states in up to six dimensions, where the dimensionality is limited only by experimental imperfections.

Q 42: Ultracold atoms, ions, and BEC V (joint session A/Q)

Time: Thursday 11:00–13:00 Location: f303

Invited Talk Q 42.1 Thu 11:00 f303

Status update of the muonic hydrogen ground-state hyperfine splitting experiment — •A. Ouf and R. Pohl on behalf of the CREMA collaboration — Johannes Gutenberg-Universität Mainz, Institut für Physik, QUANTUM & Exzellenzcluster PRISMA+, Mainz, Germany

The ground state hyperfine splitting (1S-HFS) in ordinary hydrogen (the famous 21 cm line) has been measured with 12 digits accuracy almost 50 years ago [1], but its comparison with QED calculations is limited to 6 digits by the uncertainty of the Zemach radius determined from elastic electron-proton scattering. The Zemach radius encodes the magnetic properties of the proton and it is the main nuclear structure contribution to the hyperfine splitting (HFS) in hydrogen. The ongoing experiment of the CREMA Collaboration at PSI aims at the first measurement of the 1S-HFS in muonic hydrogen (μp) with the potential for a hundredfold improved determination of the proton structure effects (Zemach radius and polarizability), which will eventually improve the QED test using the 21 cm line by a factor of 100. The experiment introduces several novel developments toward the (μp) 1s-HFS spectroscopy. We will present the current efforts of the various developments from the pulsed 6.8 μm laser, to the novel multi pass cavity, and the scintillator detection system.

[1] L. Essen *et al*, Nature **229**, 110 (1971)
[2] R. Pohl *et al.*, Nature **466**, 213 (2010)
[3] A. Antognini *et al.*, Science **339**, 417 (2013)

Q 42.2 Thu 11:30 f303

Precision Spectroscopy of an Interacting Ytterbium Fermi-Fermi Mixture — •Benjamin Abeln[1], Marcel Diem[1], Koen Sponselee[1], Nejira Pintul[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

We perform high precision spectroscopy on the $^1S_0$ to $^3P_0$ clock transition of ^{171}Yb and ^{173}Yb to investigate interactions in an ultracold Fermi-Fermi mixture of ^{171}Yb and ^{173}Yb. We find and characterize an SU(2) × SU(6) symmetric interspecies interorbital interaction. The Yb Fermi-Fermi mixture in the ground state is characterized by strongly attractive inter-species interactions, while the intra-species interactions are vanishing for ^{171}Yb and repulsive for ^{173}Yb. We discuss prospects of spectroscopic methods to gain information on the underlying many-body phase diagram.

Q 42.3 Thu 11:45 f303

Status of a buffer gas cooled Low-Emittance Laser Ablation Ion Source with two RF funnels — •Tim Ratajczyk[1], Philipp Bollinger[1], Tim Lellinger[1], Victor Varentsov[2,3], and Wilfried Nörtershäuser[1] — [1]Institut für Kernphysik, TU Darmstadt — [2]Facility for Antiproton and Ion Re- search in Europe (FAIRGmbH), Darmstadt — [3]Institute for Theoretical and ExperimentalPhysics, Moscow, Russia

Ion sources of low-emittance are of interest in many applications of experimental low-energy physics, for example as ion sources for collinear laser spectroscopy or ion trap experiments, or as ion sources for accelerators and for production of fine focusing beams for industrial microelectronics technologies. Often, surface ion sources are used due to their simple construction and easiness of operation. However, they can only deliver a very small range of elements, mostly alkaline and alkaline earth ions and a few other species. Laser ablation in vacuum opens the possibility to produce ion beams even from transition metals or compound materials. The drawback of this technique is the high emittance of the beam. The presented ion source will counteract this drawback by using He buffer gas to stop the ions and extracting them through optimized RF funnels into high vacuum conditions.

This work is supported by BMBF 05P19RDFN1 and HIC for FAIR

Q 42.4 Thu 12:00 f303

A cryogenic Penning trap system for sympathetic laser cooling of atomic ions and protons — •Johannes Mielke[1], Teresa Meiners[1], Matthias Borchert[1,3], Frederik Jacobs[1], Julian Pick[1], Amado Bautista-Salvador[2], Juan Manuel Cornejo[1], Ralf Lehnert[1,4], Malte Niemann[1], Stefan Ulmer[3], 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 — [3]Ulmer Fundamental Symmetries Laboratiory, RIKEN, Wako, Saitama 351-0198, Japan — [4]Indiana University Center for Spacetime Symmetries, Bloomington, IN 47405, USA

High precision comparisons of the fundamental properties of protons and antiprotons carried out within the BASE collaboration serve as tests of CPT invariance in the baryon sector. However, preparation and measurement schemes based on resistive cooling and image current detection are time-consuming and highly sensitive to the particle's motional energy. Thus, experimental schemes based on sympathetic cooling of single (anti-)protons through co-trapped atomic ions can contribute to the ongoing strive for improved precision through fast preparation times and low particle temperatures.

Here we present a cryogenic multi-Penning trap system for free space coupling of two single particles in an engineered double-well potential and report on latest results obtained with Doppler cooled ^{9}Be$^+$ ions. Prospects for proton loading and sympathetic cooling in a micro-coupling trap will be discussed.

Q 42.5 Thu 12:15 f303

Collinear laser spectroscopy of the $2s$ $^3S_1$ ↔ $2p$ $^3P_2$ transition in He-like Boron — •Konstantin Mohr[1], Zoran Andelkovic[2], Axel Buss[3], Volker Michael Hannen[3], Phillip Imgram[1], Kristian König[4], Jörg Krämer[1], Bernhard Maass[1], Simon Rausch[1], Rodolfo Sánchez[2], Christian Weinheimer[3], and Wilfried Nörtershäuser[1] — [1]IKP, TU Darmstadt — [2]GSI, Darmstadt — [3]IKP, WWU Münster — [4]NSCL, Michigan State University

We aim for a determination of nuclear charge radii of light isotopes in an all-optical approach, i.e., without reference to elastic electron scattering. The calculations required for this approach can currently be only accomplished for hydrogen-like systems but will soon become established for He-like systems [1]. While the ground state of He-like systems is not easily accessible by laser spectroscopy, transitions starting from the metastable $^3S_1$-state can be adressed.

The $2s$ $^3S_1$ ↔ $2p$ ^3P_j transitions of $^{11}B^{3+}$ have already been measured with a different technique [2]. At the HITRAP-facility at the GSI accelerator complex designed to prepare heavy highly charged ions for precision spectroscopy [3] we used an Electron Beam Ion Source (EBIS) and measured the $2s$ $^3S_1$ ↔ $2p$ $^3P_2$ transition in ^{10,11}B. In this contribution we report about the current status of this experiment.

[1] V. A. Yerokhin et al., Phys. Rev. **A98**, 032503 (2018)
[2] T. P. Dinneen et al., Pys. Rev. Lett. **66**, 2859, (1991)
[3] Z. Andelkovic et al., Hyp. Int. **235**, 37 (2015)

We acknowledge support from BMBF (05P19RDFAA, 05P19PMFA1) and DFG (SFB 1245).

Q 42.6 Thu 12:30 f303

Towards a high-accuracy Al$^+$ optical clock — •Johannes Kramer[1], Fabian Dawel[1], Lennart Pelzer[1], Ludwig Krinner[1], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt Braunschweig — [2]Gottfried Wilhelm Leibniz Universität Hannover

We aim to build an optical atomic clock taking advantage of the 8 mHz narrow clock transition of a single ^{27}Al$^+$ ion stored inside a linear Paul trap together with a single ^{40}Ca$^+$ ion acting as logic ion. The low sensitivity of the aluminium ion's $^1S_0$ to $^3P_0$ clock transition to external fields and its potential high Q-factor allow to reach accuracies on the level of 10^{-18}. Frequency standards with such high accuracy are candidates for a future redefinition of the SI second as well as for cm-scale resolution in measuring the gravity field of the Earth due to the gravitational redshift. In this talk we present our experimental setup as well as latest results on measuring the clock transition of the ground-state cooled Al$^+$-Ca$^+$ crystal by quantum logic protocols.

Q 42.7 Thu 12:45 f303

World's first atom interferometer with a metastable He BEC — •Oleksiy Onishchenko, Rudolf F. H. J. van der Beek, Kjeld S. E. Eikema, Hendrick L. Bethlem, and Wim Vassen — LaserLaB, Department of Physics and Astronomy, Vrije Universiteit, Amsterdam, the Netherlands

Atom interferometry has established itself as a valuable precision measurement tool for the gravitational potential, the Einstein equivalence principle, and the fine structure constant (α) among other things. While most interferometry experiements with ultracold atoms up to now have been performed with alkali or alkaline-earth atoms, metastable helium (He*) stands apart with unique advantages. Among those are the possibility to do high-accuracy atom number detection on a multichannel plate, a very small second-order Zeeman shift, and a very high critical acceleration and recoil velocity [1]. Those advantages are especially suitable for a high-precision measurement of α in a manner independent of quantum electrodynamics calculations. We experimentally demonstrate a crucial tool for such a measurement with He*, namely a large number of Bloch oscillations in an optical lattice, performed with high efficiency. This technique coherently transfers a well-known quantity of linear momentum to the atoms, which strongly reduces the uncertainty in atom recoil velocity measurements for determining α. We also demonstrate a proof-of-principle Mach-Zehnder interferometer with He*.

[1] W. Vassen *et al.* "Ultracold metastable helium: Ramsey fringes and atom interferometry". *Appl. Phys. B* **122**, 289 (2016).

Q 43: Quantum Optics and Photonics

Time: Thursday 11:00–13:00 Location: f342

Q 43.1 Thu 11:00 f342

Two-Color Ultrashort Soliton Molecules — Oliver Melchert[1,2,3], •Stephanie Willms[1,2], Surajit Bose[2], Alexey Yulin[4], Bernhard Roth[1,3], Fedor Mitschke[5], Uwe Morgner[1,2,3], Ihar Babushkin[1,2], and Ayhan Demircan[1,2,3] — [1]Cluster of Excellence PhoenixD, Welfengarten 1, 30167 Hannover, Germany — [2]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Hannover Centre for Optical Technologies, Nienburger Str. 17, 30167, Hannover, Germany — [4]Department of Nanophotonics and Metamaterials, ITMO University, 197101 St. Petersburg, Russia — [5]Institute for Physics, University of Rostock, 18059 Rostock, Germany

We present previously unreported soliton bound states in the nonlinear Schrödinger equation, whose peculiarity lies in the vastly separated center frequencies of the constituent light pulses that are bound by Kerr-forces. This kind of soliton compound exhibits peculiar analogies to quantum mechanical binding energy, vibration, dissociation and dipolelike radiation. The key point relies on a formal analogy of trapping in potential wells in quantum mechanics, which can be realized by the interaction between two incoherent ultrashort solitons. The properties of the molecule states are investigated in detail and different ways for their creation are demonstrated.

Q 43.2 Thu 11:15 f342

General framework for the analysis of imperfections in integrated nonlinear devices for quantum optics applications — •Matteo Santandrea, Michael Stefszky, and Christine Silberhorn — Integrated Quantum Optics, Paderborn University, Warburgerstr. 100, 33098, Paderborn, Germany

Integrated nonlinear (NL) devices are necessary for the efficient realisation of many quantum communication and computation protocols and their future implementation in everyday life. However, the performance metrics of these devices, such as maximum conversion efficiency and spectral purity, are drastically affected by the presence of imperfections, e.g. fabrication errors or inhomogeneous operating conditions. Therefore, it is important to study the impact of imperfections on the NL properties of integrated devices.

Here, we present a novel framework for the analysis of performance degradation in NL systems in the presence of imperfections. Our framework highlights the hidden similarities among NL processes realised in different technological platforms and is thus able to describe the behaviour of a wide variety of integrated NL systems. We show that this framework provides a simple design rule to ensure the realisation of devices with nearly ideal spectral properties and we apply it to study the impact of imperfections on the performance of lithium niobate and lithium niobate on insulator waveguides.

Q 43.3 Thu 11:30 f342

High Q-Factor double resonant Bragg-Cavities: towards efficient Second Harmonic Generation in MoS2 and WS2 — •Heiko Knopf[1,2,3], Mathias Zilk[1], Simon Bernet[2], Franz Löchner[1], Nils C. Geib[1], Tobias Vogl[1], Ulrike Schulz[2], Frank Setzpfandt[1], Sven Schröder[2], and Falk Eilenberger[1,2,3] — [1]Institute of Applied Physics, Friedrich-Schiller-University, Albert-Einstein-Straße 15, 07745 Jena — [2]Fraunhofer Institute of Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, 07745 Jena — [3]Max Planck School of Photonics, Albert-Einstein-Straße 7, 07745 Jena

Transition metal dichalcogenides (TMDCs) are 2D-materials with a direct bandgap in a range of 1.0 to 2.5 eV. They exhibit strong second-order nonlinearity per unit thickness, making them interesting for nonlinear light-conversion devices. Due to their small thickness, an interaction enhancement is, however, required for efficient operation. Here we analyze dielectric Bragg mirror based resonators (DBR) for SHG-enhancement, where the DBR provides resonances for both, the fundamental wave and the second harmonic alike. Through careful design and optimization, we optimize the design to exhibit high Q-factors. We then report on the fabrication of such cavities, with an ion-assisted deposition process. We show that high Q-factors at the pump wavelength and the second harmonic is achieved. We then demonstrate enhanced second-harmonic generation and discuss possible generalization schemes.

Q 43.4 Thu 11:45 f342

Nonlinear integrated waveguides with CVD-grown MoS2 and WS2 monolayers on exposed-core fibers — •Gia Quyet Ngo[1], Robin Klaus Tristan Schock[1], Antony George[2], Emad Najafidehaghani[2], Tobias Bucher[1], Heiko Knopf[1], Christof Neumann[2], Heike Ebendorff-Heidepriem[3], Andrey Turchanin[2], Markus Schmidt[4], and Falk Eilenberger[1] — [1]Institute of Applied Physics, Friedrich Schiller University, Jena, Germany — [2]Institute of Physical Chemistry, Friedrich Schiller University, Jena, Germany — [3]ARC Centre of Excellence for Nanoscale BioPhotonics, University of Adelaide, Australia — [4]Leibniz Institute for Photonics Technologies IPHT, Jena, Germany

We demonstrate a novel type of waveguide functionalization, where crystalline MoS2 and WS2 monolayers are directly grown on the core of exposed-core fibers (ECFs) using CVD. These fibers opens up potential applications in nonlinear optics and real-time sensing. They overcome the sub-nanometer light-matter interaction length found in free-space interaction geometries. The TMDs interact with the guided light by the evanescent field of the fiber's guided mode. The successful deposition of MoS2 and WS2 layers on the core region was observed with a light microscope, Raman- and photoluminescence-spectroscopy. The excitonic peaks were recorded in photoluminescence and transmission spectroscopy. We will present and discuss experimental data, related to the fibers capability for sensing and for enhanced nonlinear interaction.

Q 43.5 Thu 12:00 f342

Planar-Optical Polymer Transmission Line for 2D Distributed Sensing — •Axel Günther[1,3], Wolfgang Kowalsky[1,3], and Bernhard Roth[2,3] — [1]TU Braunschweig, Institute of High Frequency Technology, Schleinitzstr. 22, 38106 Braunschweig — [2]Leibniz Universität Hannover, Hannover Centre for Optical Technologies, Nienburger Str. 17, 30167 Hannover — [3]Cluster of Excellence PhoenixD (Photonics, Optics and Engineering - Innovation Across Disciplines), Hannover

Planar-optical microstructures will become important for a large variety of future applications ranging from integrated photonic sensors to short distance communication. Hereby polymers offer a various advantages such as electromagnetic immunity, biocompatibility, as well as easy and cheap fabrication capability. They also provide a high flexibility in manufacturing and design compared to their semiconductor counterparts.

We compared different coupling concepts for horizontally and vertically emitting light sources into planar polymer-optical structures including light sources and detectors to form a polymer transmission path. We focus on low-cost, easy-to-fabricate and optically efficient coupling structures. Also, a transmission line is presented which contains a side emitting laser diode coupled to polymer waveguides by self-written-waveguides. As sensing element, a photo diode chip was integrated above a grating coupler. We discuss optical characterization of the components regarding losses and signal propagation.

Q 43.6 Thu 12:15 f342

VCSEL-Based Planar Optical Near Field Sensor for Precision Measurement Applications — •Axel Günther[1,3], Bernhard Roth[2,3], and Wolfgang Kowalsky[1,3] — [1]TU Braunschweig, Institute of High Frequency Technology, Schleinitzstr. 22, 38106 Braunschweig — [2]Leibniz Universität Hannover, Hannover Centre for Optical Technologies, Nienburger Str. 17, 30167 Hannover — [3]Cluster of Excellence PhoenixD (Photonics, Optics and Engineering - Innovation Across Disciplines), Hannover

During the last years, optical information technology relying on semiconductor materials, light sources, and detectors as well as lithographic fabrication techniques gained increasing attention due to the high integration density and large transmission rates. In this field, novel sensor concepts which can easily be incorporated into an optical network array for flexible and versatile measurement, e.g., the 2D spatially resolved acquisition of physical quantities such as strain, shape deformation, and temperature, or the sensitive and specific detection of liquid and gaseous trace substances offer great application potential.

We present a new type of near-field optical sensor which has potential to be used as a high-resolution measurement device with axial resolution at the micrometer scale or below. The concept relies on an optical feedback signal generated in a VCSEL-based compound cavity and might enable fast and reliable topography determination of diverse structures. Preliminary experiments will be presented and compared to simulation results indicating the measurement capabilities of the device.

Q 43.7 Thu 12:30 f342

Nanophotonic tantalum pentoxide devices for integrated quantum technology — •Martin A. Wolff[1,2,3,4], Lukas Splitthoff[1,2,3], Thomas Grottke[1,2,3], Simon Vogel[1,2,3], and Carsten Schuck[1,2,3] — [1]Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]SoN - Center for Soft Nanoscience, Busso-Peus-Str. 10, 48149 Münster, Germany — [4]martin.wolff@wwu.de

Tantalum Pentoxide (Ta2O5) is a new dielectric material system for realizing all key functionalities required for a versatile quantum technology platform on silicon chips. Here we show active and passive photonic integrated circuit components for realizing reconfigurable nanophotonic networks from Ta2O5 thin-films on insulator. Low-loss waveguides, wide-band grating couplers, micro-ring resonators with high quality factors of 356,000 and tunable directional couplers provide crucial passive linear optic functionality. Nanoelectromechanical phase shifters further enable active functionality, thus allowing for network reconfigurability, feedback and feedforward control as desired in many quantum technology applications. Waveguide-integrated superconducting nanowire single-photon detectors with efficiencies of 86% complement the quantum photonic toolbox. Our work paves the way for realizing the full suite of photonic integrated quantum technology applications with Ta2O5 nanophotonic devices.

Q 43.8 Thu 12:45 f342

Nanophotonic inverse design: A dynamic binarization function for the "objective-first" algorithm — •Marco Butz[1,2,3] and Carsten Schuck[1,2,3] — [1]Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]SoN - Center for Soft Nanoscience, Busso-Peus-Str. 10, 48149 Münster, Germany

Photonic integrated circuits are being employed for an increasing number of complex quantum optics experiments on compact and interferometrically stable chips. The integration of ever-increasing numbers of circuit components poses challenging requirements on the footprint and performance of individual nanophotonic devices. Here we show how inverse design algorithms based on the "objective-first" method can be employed for finding highly efficient and compact device layouts. We improve on existing implementations by introducing a dynamic binarization penalty function that removes limitations in the iterative evolution of the algorithm towards an efficient solution. We exploit the dynamic binarization in the design of waveguide mode converters with high efficiency and small footprint that outperform existing designs relying on intuitive design concepts and brute force optimization. It is straightforward to adapt our approach for a wide range of circuit components, thus providing new possibilities for scaling nanophotonic networks to large system size as well as realizing novel functionalities in such networks.

Q 44: Laser Development and Applications

Time: Thursday 11:00–13:00 Location: f435

Q 44.1 Thu 11:00 f435

VECSEL system for quantum manipulation of trapped magnesium ions — •Till Rehmert[1,2], Maximilian J. Zawierucha[2], Jan Christoph Heip[2], Fabian Wolf[2], and Piet O. Schmidt[1,2] — [1]Leibniz Universität Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Optical pumped vertical-external-cavity surface-emitting lasers (VECSEL) have been demonstrated to be a promising technology for applications ranging from spectroscopy to quantum computing and quantum simulation [1]. VECSELs combine compact size and high optical power and the advantage of a wide wavelength coverage.

We present the steps towards a high power VECSEL system with an optical-to-optical effciency of approximately 30% and up to 6 watts of optical output power at 1121 nm. Furthermore, an overview of the spectral properties and the noise levels of frequency and intensity will be given.

A VECSEL system at this wavelength is a suitable light source for quantum logic spectroscopy with trapped magnesium ions, since it offers frequency quadrupled in the UV enough output power and a laser linewidth of tens of MHz for Doppler cooling, repumping and Raman transition.

[1] Burd et al, Optica Vol.3, No. 12 (2016)

Q 44.2 Thu 11:15 f435

Femtosecond writing of waveguides structures inside polymers. — •Dmitrii Perevoznik[1,2] and Uwe Morgner[1,2,3] — [1]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering - Innovation AcrossDisciplines), Hannover, Germany" — [3]Hannover, Germany" Laser Zentrum Hannover e.V., Hollerithalle 8, D-30419 Hannover, Germany

At present optical technology is one of the most rapidly developing areas of science and technology. Continuously increasing demands of the society for high-speed and reliable systems of information transmission have led to the development of waveguide optics and of methods for creation of waveguides in different media. Easiest way of creating waveguides and complex waveguide networks in different media is direct femtosecond writing. Writing waveguides in polymers is a just developing field, polymer materials are very cheap and have the potential to create complex structures inside the volume of the material. In polymers the refractive index increase is induced by material compression and stress-related effects which are caused by a quickly expanding plasma core. Once the modification is done, there is an area where material is compressed and the index increased. This area can be used as optical waveguide. In this work we want to demonstrate different waveguide structures which can be produced inside polymer materials.

Q 44.3 Thu 11:30 f435

Selective Hermite-Gaussian mode excitation in a laser cavity by external pump beam shaping — •Florian Schepers[1], Tim Bexter[1], Tim Hellwig[1], and Carsten Fallnich[1,2] — [1]Institute of Applied Physics, University of Münster, Germany — [2]MESA+ Institute of Nanotechnology, University of Twente, The Netherlands

An improved gain-shaping method for selective mode excitation is presented and its application for the excitation of higher-order Hermite-Gaussian modes is demonstrated in an end-pumped Nd:YVO4 laser. Using a digital micromirror device, the intensity distribution of the pump beam within the laser crystal could be shaped with a high degree of freedom. Thus, a broad variety of different gain distributions were achieved, enabling a highly selective mode excitation method based on gain shaping. In the presented experiment, the excitation of nearly 1000 different Hermite-Gaussian modes was demonstrated, increasing the number of excitable Hermite-Gaussian modes by at least a factor of five, compared to other excitation methods [1-3]. The excited modes include Hermite-Gaussian modes of high orders as, for example, the $HG_{25,27}$ mode. Furthermore, the electronic control of the gain profile, applied via the digital micromirror device, enabled automated measurements of the selective mode excitation. Here, a systematic study is presented to optimize the generated pump patterns with respect to the number of modes that could be excited.

[1] H. Laabs et al., Opt. Laser Technol. 28, 213-214 (1996)

[2] W. Kong et al., Opt. Lett. 37, 2661-2663 (2012)
[3] S. Ngcobo et al., Nat. Commun. 4, 2289 (2013)

Q 44.4 Thu 11:45 f435

High-Order and Multi-Line Transverse Mode Locking of an End-Pumped Solid-State Laser — •Florian Schepers[1] and Carsten Fallnich[1,2] — [1]Institute of Applied Physics, University of Münster, Germany — [2]MESA+ Institute of Nanotechnology, University of Twente, The Netherlands

Transverse mode locking (TML) was demonstrated for the first time by Auston [1] in 1968, generating a fast scanning beam in the transverse direction of the cavity by locking the phases of multiple transverse modes.
In this talk we demonstrate a three times broader beam scanning range in comparison to previous results [2] by implementing TML in an end-pumped solid-state laser using an acousto-optic modulator. This improvement was accomplished by both, a large effective open aperture of the gain medium and a line-shaped pump light distribution, providing gain for a high number of transverse modes and thus enabling an increase of the central mode number $\bar{n}$ of the TML-process from $\bar{n} = 4$ to $\bar{n} = 36$. Furthermore, we realized a beam that was scanning synchronously on multiple parallel lines by being operated on a single higher-order mode in the orthogonal direction of the TML-process.

[1] D. Auston, IEEE J. Quantum Electron. **4**, 471–473 (1968)
[2] C. Haug et al., IEEE J. Quantum Electron. **10**, 406-408 (1974)

Q 44.5 Thu 12:00 f435

Stimulated Raman Scattering Spectroscopy on Microplastic Particles with a Noncollinear Optical Parametric Oscillator — •Luise Beichert[1,2], Yuliya Binhammer[1,2], José Ricardo Andrade[1,2], and Uwe Morgner[1,2] — [1]Leibniz Uni Hannver, Institut für Quantenoptik, Hannover, Germany — [2]Cluster of Excellence PhoenixD, Hannover, Germany

Microplastics are widely spread in our global environment. We find them not only in our oceans and inland waters all over the world but also increasingly in our drinking water. Femtosecond Optical Parametric Oscillators are very suitable for microscopy and spectroscopy experiments due to their broadband tuning range at high output power. Noncollinear optical parametric oscillators (NOPOs) provide a good scalability in terms of output power, repetition rate and pulse energy. The instantaneous broadband frequency conversion combined with the special phase matching geometry in the nonlinear crystal enables a fast tunability without readjustment.

Here, we present an IR-NOPO with a fastly tunable output spectrum between 750 and 950 nm. It can adress Raman transitions in the range of 800-3500 cm^{-1} in less than 10 ms. We show SRS-spectra of different plastic particles in video rates.

Q 44.6 Thu 12:15 f435

Linewidth-reduced DBR laser for Raman sideband cooling — •Pooja Malik, Lukas Ahlheit, Wolfgang Alt, Maximilian Ammenwerth, Tobias Macha, Deepak Pandey, Hannes Pfeifer, Eduardo Uruñuela, and Dieter Meschede — Institut für Angewandte Physik, Wegelerstr. 8, 53115, Bonn, Germany

Raman sideband cooling is an established ground state cooling technique, especially suited for experiments involving one or few atoms. It uses a two photon Raman transition that is driven by two lasers phase locked at around the hyperfine splitting of the atomic species. This is implemented in our experiment with Rb87 atoms that are trapped inside a fiber Fabry-Pérot cavity for photon storage experiments [1]. One of the employed Raman lasers is a DBR laser that offers a mode hop free tuning range of hundreds of GHz. Phase locking is however hampered by the large intrinsic linewidth of some MHz. Here we show how this limitation can be overcome by using an external optical feedback reducing the linewidth of our DBR laser [2], while maintaining its GHz tuning range. By means of a delayed self heterodyne method supported by a numerical noise model [3], we identify different noise components and the Lorentzian linewidth below 30kHz. We demonstrate near ground state cooling of single atoms using this linewidth-reduced laser.

[1] T. Macha et al., arXiv:1903.10922v2 (2019)
[2] Q. Lin et al., Opt. Lett. 37, 1989-1991 (2012)
[3] W. Ma et al., Appl. Opt. 58, 3555-3563 (2019)

Q 44.7 Thu 12:30 f435

Argon Trap Trace Analysis: Radiometric dating of environmental samples with applied quantum technology — •Lisa Ringena[1], Julian Robertz[1], Maximilian Schmidt[1,2], Niccolo Rigi-Luperti[1], Florian Sandel[1], Jeremias Gutekunst[1], Arne Kersting[2], Yannis Arck[2], David Wachs[2], Annabelle Kaiser[2], Werner Aeschbach[2], and Markus Oberthaler[1] — [1]Kirchhoff Institute for Physics, Heidelberg, Germany — [2]Institute for Environmental Physics, Heidelberg, Germany

The measurement of the radioisotope ^{39}Ar opens a unique path towards dating of environmental samples from the last millennium, due to 269 years half-life, chemical inertness and well-known atmospheric concentration. However, its low relative abundance of ^{39}Ar/Ar $\sim 8*10^{-16}$ hinders the use of standard analysis schemes. Argon Trap Trace Analysis (ArTTA) enables detection by employing the isotopic shift in the resonance frequency of an optical dipole transition. The trapping of ^{39}Ar inside a magneto-optical trap grants perfect selectivity due to a multitude of resonant scattering processes. In the trap, single ^{39}Ar atoms are captured and counted, while the huge background of abundant isotopes remains unaffected. During the last years, the apparatus was successfully used to study groundwater, ocean, ice and lake water samples. A second machine for higher throughput is currently set up, the status of which will be presented. In respect of the original ArTTA dating apparatus, the state of the art regarding sample size limits and measurement uncertainty will be discussed.

Q 44.8 Thu 12:45 f435

Optical bend sensor based on micro-structured polymer optical fibres — •Lennart Leffers[1], Kort Bremer[1], Bernhard Roth[1], and Ludger Overmeyer[2] — [1]Hannover Centre for Optical Technologies, Leibniz Universität Hannover, Nienburger Straße 17, 30167 Hannover, Germany — [2]Institute of Transport und Automation Technology, Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany

We investigate a highly flexible and elastic bend sensor based on polymer optical fibre (POF) with Bragg grating (BG) structures. The concept is very simple and relies on the inscription of BG structures eccentrically into a graded-index (GI) multi-mode (MM) POF via contact exposure with a phase mask and a KrF excimer laser in the UV. Depending on the deformation of the POF, the lattice constant of the inscribed BG is compressed or strained due to its position relative to the fibre core. This in turn will result in a red or blue shift of the Bragg wavelength, respectively. Therefore, with a single BG the deformation in one axis can be observed. Moreover, multiple BGs inscribed into the same POF at different positions would allow to determine the shape deformation of the POF relative to a reference frame. Consequently, this technology could form the basis for new applications in the areas of robotics, augmented reality or in medical diagnostics, for example, the monitoring of the neurological movement disorder *focal dystonia*.

Q 45: Quantum Effects (QED) II

Time: Thursday 11:00–13:00 Location: f442

Q 45.1 Thu 11:00 f442

Quantum friction and internal atomic dynamics — •Nico Strauss and Stefan Yoshi Buhmann — Albert-Ludwigs-Universität Freiburg

The Casimir-Polder force between atoms is of quantum mechanical origin and forms the basis of quantum friction, which is predicted to occur when two objects move at distance on the order of a few tens of nanometers relative to each other. In this presentation, we consider the effects of this force on the energy levels of atoms and their velocity dependence as well as that of the resulting transition frequencies [1]. We investigated how this frequency dependence can be observed in the experiments of M. Ducloy and M. Fichet [2] by measuring the changes in the reflection coefficients of a modulated laser beam incident on the boundary between a dielectric and a gas moving atoms.

[1] J. Klatt, R. Bennett and S. Y. Buhmann, Phys. Rev. A 94,

063803 (2016).
[2] M. Ducloy and M. Fichet, J. Phys. II, 1529 (1991).

Q 45.2 Thu 11:15 f442

Theory of quantum vacuum detection — •Frieder Lindel[1], Robert Bennett[1,2], and Stefan Yoshi Buhmann[1,2] — [1]Institute of Physics, University of Freiburg — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

When quantising the electromagnetic radiation field, one of the most fascinating consequences is the existence of fluctuations associated with the ground state. These vacuum fluctuations manifest themselves indirectly through their influence on matter where they may be regarded as responsible for important processes, e.g. spontaneous emission, the Lamb shift, and the Casimir force. More recently, an alternative route to observing the quantum vacuum has been developed in electro-optic sampling experiments: they are based on the output statistics of ultrashort laser pulses sent through nonlinear crystals whose optical properties are influenced by the vacuum fluctuations [1,2].

In my talk, I will report on the development of a theoretical framework based on macroscopic quantum electrodynamics which is capable of describing the output statistics of electro-optic sampling experiments accounting for absorption, dispersion and general optical environments. It is in good agreement with available experimental data and recovers previous theoretical findings in certain limits. Furthermore, I will discuss how it can be exploited in order to serve as a convenient tool for detailed studies of the full polaritonic QED ground state in general environments.

[1] C. Riek et al., Science 350, 420 (2015)
[2] I.-C. Benea-Chelmus et al., Nature 568, 7751 (2019)

Q 45.3 Thu 11:30 f442

On the Heisenberg limit for detecting vacuum birefringence — •Naser Ahmadiniaz[1] and Ralf Schutzhold[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institut fur Theoretische Physik, Technische Universitat Dresden, Dresden, Germany

Quantum electrodynamics predicts the vacuum to behave as a nonlinear medium, including effects such as birefringence.

However, for experimentally available field strengths, this vacuum polarizability is extremely small and thus very hard to measure.

In analogy to the Heisenberg limit in quantum metrology, we study the minimum requirements for such a detection in a given strong field (the pump field).

Using a laser pulse as the probe field, we find that its energy must exceed a certain threshold depending on the interaction time.

However, a detection at that threshold, i.e., the Heisenberg limit, requires highly non-linear measurement schemes – while for ordinary linear-optics schemes, the required energy (shot noise limit) is much larger.

Finally, we discuss several experimental scenarios in this respect.

Q 45.4 Thu 11:45 f442

Many-body photon bound state propagation in waveguide QED — Sahand Mahmoodian[1], •Giuseppe Calajó[2], Darrick Chang[2], Klemens Hammerer[1], and Anders Sørensen[3] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Germany — [2]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Spain — [3]Niels Bohr Institute, University of Copenhagen, Denmark

Generating many-body states of light is an outstanding challenge in quantum optics. One of the main obstacles in the pursuit of this goal has been developing a system with a sufficiently strong nonlinear response. In this talk, we show that two-level atoms chirally coupled to a waveguide provide an ideal platform to observe quantum many-body states of photons. By computing the propagation of light through this system, we show that of central importance are the class of photon bound states with a well-defined photon number n, which propagate with a photon-number-dependent group-delay scaling as $1/n^2$. This leads to input coherent pulses of light becoming spatially separated after interacting with sufficiently many atoms. We also show that, in the classical limit, the photon bound states map onto the soliton solutions of self-induced transparency. Our many-body theory is able to capture the entire spectrum of behaviour from few-photon quantum propagation, genuine many-body photon dynamics, and finally, the quantum-to-classical transition. This physics can be potentially demonstrated in state-of-the art circuit QED and nanophotonic experiments.

Q 45.5 Thu 12:00 f442

Enhanced coherent atom-photon interaction in a hollow-core light cage — •Esteban Gómez-López[1], Flavie Davidson-Marquis[1], Bumjoon Jang[2], Tim Kroh[1], Chris Müller[1], Mario Ziegler[2], Julian Gargiulo[3], Stefan A. Maier[3], Harald Kübler[4], Markus A. Schmidt[2,5], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin — [2]Leibniz Institute of Photonic Technology, Jena — [3]Ludwig-Maximilians-Universität München — [4]University of Stuttgart — [5]Otto Schott Institute of Material Research, Jena

Quantum memories and repeaters are needed to overcome the unavoidable losses in the channels of quantum networks [1]. For this, atomic vapor cells provide a relatively easy to handle platform [2]. In this work we show for the first time coherent interaction between Cs atoms and light in a hollow-core light cage [3]. The tight confinement of the light in the cage placed inside a warm vapor cell leads to a significantly enhanced interaction strength compared to a freely propagating beam. Measurements of Electromagnetically Induced Transparency (EIT) transmission profiles show a clear deviation from the weak probe approximation predictions. We discuss these deviations and show generalized theoretical simulations, which provide a better fit to the measured spectra. The experiments set the base for delaying light pulses using EIT in a chip-integrated, easy-to-fill, device, and to the implementation of a compact quantum memory using the EIT-storage scheme. [1] Phys. Rev. Lett. 81, 5932 (1998). [2] Phys. Rev. Lett. 107, 053603 (2011). [3] ACS Photonics 6, 649 (2019).

Q 45.6 Thu 12:15 f442

Photon dynamics in a one-dimensional waveguide coupled to a chain of atoms — •Jan Kumlin and Hans Peter Büchler — Institute for Theoretical Physics III, University of Stuttgart, 70550 Stuttgart, Germany

In this talk, we discuss the photon dynamics inside a one-dimensional waveguide that is coupled to a chain of two-level atoms. It is possible to realise a chiral system where time-reversal symmetry is broken by selectively coupling only to the forward propagating modes of the waveguide.

By integrating out the photonic degrees of freedom, we derive an effective master equation for the atomic degrees of freedom. The system's dynamics can then be described by dissipative terms characterising the collective emission of photons and coherent interaction due to the exchange of virtual photons. In the chiral system, the character of this interaction is fundamentally different compared to a non-chiral system and we discuss the dynamics for both cases.

Introducing an additional classical light field to couple to a third level for each atom, we also show an alternative derivation of electromagnetically induced transparency and slow light in a perfectly chiral waveguide. Furthermore, we discuss the effects when the chirality is broken and backscattering is taken into account.

Q 45.7 Thu 12:30 f442

Tailoring a Single Photon with an Atomic Frequency Comb — •Tom Schmit, Luigi Giannelli, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

Quantum memories are storage units for flying qubits such as single photons [1] and they are one of the key ingredients for building a quantum network [2]. Memories based on solid-state media, such as rare-ion doped crystals, are promising due to their coherence properties. Among the protocols that have been developed for solid-state memories is the *Atomic Frequency Comb* (AFC) protocol [3]. Here, a given absorption line of the medium is spectrally shaped such that it consists of a series of narrow peaks. In this work we theoretically explore the perspectives of an AFC to tailor the temporal and spectral shape of the photon that is retrieved from the memory. We determine the shape of the comb that is required for generating a target photon of arbitrary shape and discuss some specific examples.

[1] N. Sangouard and H. Zbinden, Jour. of Mod. Opt., **59:17**, 1458-1464 (2012).
[2] H. J. Kimble, Nature **453**, 1023 (2008).
[3] M. Afzelius, C. Simon, H. de Riedmatten, and N. Gisin, Phys. Rev. A, **79**, 052329 (2009).

Q 45.8 Thu 12:45 f442

Control of directionality in photon storage — •Martin Korzeczek and Daniel Braun — University Tübingen - Institute for Theoretical Physics, Tübingen, Germany

When storing light pulses in atomic clouds, emission directionality is usually determined fully by the signal and control pulse directionality. Making use of the fact that the spin wave encodes the pulse directionalities in complex phases in Hilbert space, we propose a method of manipulating these phases and achieving arbitrary emission directions. Using a fully 3d numerical model and Gaussian pulses, we analyse the scaling of storage efficiency and its dependence on pulse directionality and cloud parameters. Additionally to determining the emission directionality, the phases in Hilbert space play a role in the degradation of the spin wave. Controlling them opens up the possibility of avoiding this source of state degradation, which adds to the methods for improving storage time.

Q 46: Nano-Optics (Single Quantum Emitters) II

Time: Thursday 14:00–16:00 Location: a310

Q 46.1 Thu 14:00 a310

Optical studies of silicon-vacancy color centers in phosphorus-doped diamond — •Florian Sledz[1], Assegid M. Flatae[1], Stefano Lagomarsino[1], Navid Soltani[1], Shannon S. Nicley[2], Ken Haenen[2], Robert Rechenberg[3], Michael F. Becker[3], and Mario Agio[1] — [1]Laboratory of Nano-Optics and Cμ, University of Siegen, Siegen, Germany — [2]Institute for Materials Research (IMO) & IMOMEC, Hasselt University & IMEC vzw, Diepenbeek, Belgium — [3]Fraunhofer USA Center for Coatings and Diamond Technologies, East Lansing, USA

A robust single-photon source operating upon electrical injection at ambient condition is desirable for quantum technologies. Silicon-vacancy (SiV) color centers in diamond are promising candidates as their emission is concentrated in a narrow zero-phonon line with a short excited-state lifetime of ~1 ns [1]. Creating the color centers in n-type diamond (phosphorus-doped) allows the implementation of a Schottky-diode configuration. This provides a simpler approach than the traditional complex diamond semiconductor junctions (e.g., p-i-n). We optically characterize SiV color centers in different phosphorus-doped diamond and show that the background due to doping, nitrogen impurities, and defects induced by Si-ion implantation can be significantly suppressed for single-photon emission [2]. This paves a way for the realization of the predicted bright electroluminescence of SiV color centers [3]. References: [1]. Lagomarsino et al, Diam. Relat. Mater. 84, 196 (2018). [2]. Flatae et al, manuscript in preparation (2019). [3]. Fedyanin and Agio, New J. Phys. 18, 073012 (2016).

Q 46.2 Thu 14:15 a310

Molecule-photon interactions in phononic environments — •Michael Reitz, Christian Sommer, Burak Gurlek, Diego Martin-Cano, Vahid Sandoghdar, and Claudiu Genes — Max Planck Institute for the Science of Light, Staudtstraße 2, D-91058 Erlangen, Germany

Molecular spectroscopy in the solid-state crucially depends on the interaction of electronic degrees of freedom with the surrounding environment. Processes involving absorption and emission of free space or spatially confined photons are strongly influenced by the coupling of electrons to intramolecular vibrations (vibrons) and to crystal vibrations (phonons). We describe light-matter interactions of guest molecules placed inside a host crystal environment including finite thermal occupancies of vibrons and phonons and provide analytical expressions for absorption and emission spectra derived within the formalism of quantum Langevin equations. We find that vibron-phonon couplings lead to a generally non-Markovian vibrational relaxation dynamics and that the common coupling to a continuum of bulk phonons can mediate collective vibron-vibron interactions similar to the processes of sub- and superradiance characterizing radiative transitions. On platforms showing confined optical modes we analytically derive quantities for molecular polaritonics such as the imprint of vibronic and electron-phonon coupling onto the output field and derive effective polariton cross-talk rates for finite baths occupancies.

Q 46.3 Thu 14:30 a310

A narrow-band fiber-coupled single photon source with a single organic molecule. — •Vladislav Bushmakin[1,2], Guilherme Stein[1], Yijun Wang[1], Jörg Wrachtrup[1,2], Andreas Schell[3], and Ilja Gerhardt[1,2] — [1]Universität Stuttgart, 3. Physikalisches Institut, Pfaffenwaldring, 57, 70569, Stuttgart, Germany — [2]Max-Plank-Institut für Festkörperforschung, Heisenbergstraße 1, 70569 Stuttgart, Germany — [3]Leibniz Universität Hannover, Institut für Festkörperphysik, Appelstraße, 2, 30167, Hannover, Germany

A single-photon source is an essential tool for the emerging field of quantum technologies. Ideally, it should be spectrally compatible with other photonic devices while providing a high flux of narrow-band photons. A single organic dye molecule dibenzanthanthrene (DBATT, $C_{30}H_{16}$) embedded into a n-tetradecane Spol'skiĭ matrix under cryogenic conditions possesses the given characteristics, hence constitutes a prominent single-photon source. Nevertheless, the implementation of such a single-photon source requires a complex experimental setup involving a cryostat with a confocal microscope for the effective collection of the molecular emission. Another approach is to use a single emitter coupled directly to the end facet of an optical fiber. This approach has the potential to transfer a single-photon source based on a quantum emitter from a proof-of-principle type of setup to a scalable "plug-and-play" device. Here we present a successful coupling of a single organic molecule to an optical fiber [1].

[1] G.Stein *et al.*, A narrow-band sodium-resonant fiber-coupled single photon source, https://arxiv.org/abs/1909.08353 (2019)

Q 46.4 Thu 14:45 a310

Creating long lived quantum coherence in organic molecules — Burak Gurlek, Vahid Sandoghdar, and •Diego Martín-Cano — Nano-Optics Division, Max Planck Institute for the Science of Light, Erlangen, Germany.

Polycyclic aromatic hydrocarbons stand out within the select group of solid-state emitters with remarkable coherent properties for quantum processing at optical frequencies [1]. These molecules behave as effective two-level emitters embedded in organic crystals, a property that has been exploited to show fundamental devices and nonclassical states at the level of few photons [1-3]. So far, such demonstrations have mainly focused on the coherent electronic transitions of the molecules because their vibrational levels dissipate at faster time scales and thus behave as incoherent decay channels. In this work, we investigate the vibrations of organic crystals theoretically. Importantly, we show that engineering the phononic environment enables an increase in the coherence of the vibrational levels of embedded molecules by orders of magnitude. This finding holds promise for long quantum storage and unexplored quantum functionalities in these systems. **References:** [1] B. Kozankiewicz and Michel Orrit, Chem. Soc. Rev. 43, 1029 (2014). [2] D. Wang, H. Kelkar, D. Martin-Cano, T. Utikal, S. Götzinger, V. Sandoghdar, Phys. Rev. X 7, 021014 (2017). [3] D. Wang, et al., Nature Phys. 15, 483 (2019).

Q 46.5 Thu 15:00 a310

Cavity coupled nano scale quantum emitter for integrated photonic circuits — •Philip P.J. Schrinner[1], Jan Olthaus[2], Doris Reiter[2], and Carsten Schuck[1] — [1]Physikalisches Institut and Center for Nanotechnology, WWU Münster, Germany — [2]Institut für Festkörpertheorie, Universität Münster, 48149 Münster, Germany

Integrated quantum photonics with single photons in nano-photonic waveguides is a promising approach for quantum sensing, computing and communication. Despite current nano-technological advances, efficient and scalable coupling of single-photon sources to photonic integrated circuits remains a major hurdle. Here, we employ 1D photonic crystal cavities for efficiently interfacing NV centers in nano-diamonds with nano-photonic waveguides [1]. We fabricate nano-photonic devices from Ta2O5 thin films, use a lithographic technique for precise emitter-positioning and characterize the coupling via lifetime measurements. We find Q-factors of several thousands and lifetime reductions for single NV centers by a factor of three due to the Purcell effect. Our work paves the way for integrating large numbers of single emitters into nano-photonic networks for complex quantum optics experiments. [1] Olthaus et al., Adv. Quantum Technol. 2019, 1900084

Q 46.6 Thu 15:15 a310

Optimal Photonic Crystal Cavities for Coupling Nanoemitters to Photonic Integrated Circuits — •Jan Olthaus[1], Philip

P. J. Schrinner[2], Carsten Schuck[2], and Doris E. Reiter[1] — [1]Institute of Solid State Theory, University of Muenster — [2]Physics Institute, University of Muenster

Photonic integrated circuits hold great promise for realizing scalable quantum technologies. On-chip implementation of those circuits requires an efficient interface between quantum emitters and nanophotonic devices. Such an interface can be provided using photonic crystal nanobeam cavities, which combine wavelength-scale mode volumes with high quality factors.

We show that the design and fabrication of photonic crystal nanobeam cavities in the visible wavelength regime is possible directly on-substrate. Our cavities are designed to host NV-centers in nanodiamonds. We stress that the on-substrate design allows compatibility with modern fabrication processes. Three different cavity geometries based on a mode-matching and a deterministic design approach are optimised using 3D-FDTD simulations. Here, we present the optimization strategies and the resulting parameters. Using the optimized parameters, we verify the theoretical predictions experimentally, finding a reasonable agreement. In our case the mode-matching approach is found advantageous for on-substrate realizations.

Our results pave the way for integrating quantum emitters with nanophotonic circuits for applications in quantum technologies.

[1] Adv. Quantum Technol. 1900084 (2019).

Q 46.7 Thu 15:30 a310

Nitrogen Vacancy Center Coupled to a Hybrid Bullseye Grating, a Highly Directional Single Photon Source — •Niko Nikolay[1], Boaz Lubotzky[2], Hamza Abudayyeh[2], Florian Böhm[1], Ronen Rapaport[2], and Oliver Benson[1] — [1]AG Nanooptik & IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]The Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 9190401, Israel

In recent years the Nitrogen Vacancy center (NV) in diamond has proven to be a particularly effective tool to sense magnetic fields [1]. In laboratory environments, e.g. solid immersion lenses or high NA oil immersion lenses are often used to capture as many photons as possible because the sensing sensitivity scales with the count rate. However, these collection techniques are not always optimal as they usually require to excite and detect through the substrate. We discuss a single photon source prototype giving high collection efficiencies and potentially high fiber coupling efficiencies using air objective lenses. This source consists of a NV coupled to a slab waveguide which is supported by a bullseye grating. In addition to the working principle of the antenna [2], we discuss the NV positioning technique [3] and show an experimental characterization of single photon source.

[1] Pham, Linh My, et al., NJP 13.4 (2011): 045021.
[2] Abudayyeh, et al., QST 2.3 (2017): 034004.
[3] Nikolay, Niko, et al., APL 113.11 (2018): 113107.

Q 46.8 Thu 15:45 a310

Next-generation single-photon sources for satellite-based quantum communication — •Tobias Vogl[1,2], Ruvi Lecamwasam[3], Ben Buchler[3], Yuerui Lu[3], Ping Koy Lam[3], and Falk Eilenberger[1] — [1]Friedrich-Schiller-Universität — [2]University of Cambridge — [3]Australian National University

Color centers in solid state crystals have become a frequently used system for single-photon generation, advancing the development of integrated photonic devices for quantum optics and quantum communication applications. Recently, defects hosted by two-dimensional (2D) hexagonal boron nitride (hBN) attracted the attention of many researchers, due to its chemical and thermal robustness as well as high single-photon luminosity at room temperature. Here, we present recentadvances in engineering this new type of emitter. The quantum emitter is coupled with a nanophotonic cavity, improving its performance so that the single-photon source is feasible for practical quantum information processing protocols. The cavity-coupled device is characterized by an increased collection efficiency and quantum yield, combined with off-resonant noise suppression and improvement of photophysics. Moreover, the complete source, including all control units and driving electronics is implemented on a 1U CubeSat platform. An application of particular interest is satellite-based single-photon quantum key distribution. Simulations predict the performance of the source is sufficient to outperform conventional decoy state protocols. We will also show results on the first ever quantum information experiment involving single-photons from hBN.

Q 47: Ultra-cold plasmas and Rydberg systems II (joint session A/Q)

Time: Thursday 14:00–15:45 Location: a320

Invited Talk Q 47.1 Thu 14:00 a320

Anderson localization in a Rydberg composite — •Matthew Eiles, Alexander Eisfeld, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, 38 Noethnitzer Str. Dresden 01187

We demonstrate the localization of a Rydberg electron in a Rydberg composite, a system containing a Rydberg atom coupled to a structured environment of neutral ground state atoms. This localization is caused by weak disorder in the arrangement of the atoms and increases with the number of atoms M and principal quantum number ν. We develop a mapping between the electronic Hamiltonian in the basis of degenerate Rydberg states and a tight-binding Hamiltonian in the so-called "trilobite" basis, and then use this concept to pursue a rigorous limiting procedure to reach the thermodynamic limit in this system, taken as both M and ν become infinite, in order to show that Anderson localization takes place. This system provides avenues to study aspects of Anderson localization under a variety of conditions, e.g. for a wide range of interactions or with correlated/uncorrelated disorder.

Q 47.2 Thu 14:30 a320

Rydberg Dressed Quantum Many-Body Systems — •Nikolaus Lorenz[1], Lorenzo Festa[1], Lea Steinert[1], Philip Osterholz[1], Joop Adema[1], Robin Eberhard[1], and Christian Gross[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching — [2]Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

Neutral atoms in microtrap arrays brought to interaction by Rydberg coupling offer a novel platform to study quantum magnetism. We have constructed a new experiment with potassium atoms, which aims to induce the magnetic interactions via near-resonant Rydberg coupling, so called Rydberg dressing. Here we report on coherent Rydberg coupling in a two dimensional array of single atoms. We observe fast coherent Rabi oscillations of single atoms as well as of small Rydberg superatoms. Finally we discuss first experiments towards Rydberg dressing induced interactions among atomic ground states.

Q 47.3 Thu 14:45 a320

Extended coherently delocalized states in a frozen Rydberg gas — •Ghassan Abumwis, Matthew T. Eiles, and Alexander Eisfeld — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The long-range dipole-dipole interaction between excited Rydberg states of atoms can create highly delocalized states due to the exchange of excitation between the atoms. We show that even in a random gas many of the single-exciton eigenstates are surprisingly delocalized, composed of roughly one quarter of the participating atoms. We identify two different types of eigenstates: one which stems from strongly-interacting clusters, resulting in localized states, and one which extends over large delocalized networks of atoms. These two types of states can be excited and distinguished by appropriately tuned microwave pulses, and their relative contributions can be modified by the Rydberg blockade. The presence of these delocalized eigenstates could be relevant to puzzling results in several current experiments.

Q 47.4 Thu 15:00 a320

Characterizing molecular symmetries with quantum gas microscopy — •Simon Hollerith[1], Jun Rui[1], Antonio Rubio-Abadal[1], David Wei[1], Kritsana Srakaew[1], Simon Evered[1], Christian Gross[1,2], and Immanuel Bloch[1,3] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching — [2]Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen — [3]Fakultät für Physik, Ludwig-Maximilians-Universität

München, 80799 München

Rydberg macrodimers - molecules consisting of two bound highly excited Rydberg atoms - provide enormous bond lengths even resolvable with optical wavelengths. Here we report on a microscopic study of macrodimers with different molecular symmetries in a gas of ultracold atoms in an optical lattice. The bond length of about 0.7 micrometers matches the diagonal distance of two atoms in the lattice. The geometry of the two-dimensional lattice initially unity filled with ground state atoms allows to control the relative orientation of the molecular axis to an ambient magnetic field and the polarization of the photoassociation light. Using our spatially resolved detection, we detect the associated molecules by correlated atom loss and find the excitation rates to be in agreement with theoretical predictions. Furthermore, we present how the molecular excitation rate can be significantly increased by the use of two color photoassociation. Our results highlight the potential of quantum gas microscopy for molecular physics and show how macrodimers might be used to study many body physics.

Q 47.5 Thu 15:15 a320

energy level statistics in Rydberg Composites — •Andrew Hunter, Matthew Eiles, Alex Eisfeld, and Jan M Rost — Max Planck Institute for the Physics of Complex Systems

Rydberg Composites are a new class of Rydberg matter consisting of a single Rydberg atom interfaced with a dense environment of neutral ground state atoms organized in a lattice [1]. The properties of the Rydberg composite are directly linked to the discrete symmetry of the occupied sites in the lattice with characteristic but unusual footprints of quantum chaos in the energy level statistics of the composite. We have developed techniques to identify these effects and present a systematic study of broken lattice symmetry and the transition to full chaos as atoms are removed from the lattice. We also describe how these statistics change with decreasing lattice constant with a transition to a continuous environment when the Rydberg electron can no longer resolve the lattice spacing.

[1] Hunter A L, Eiles M T, Eisfeld A and Rost J M 2019 arXiv:1909.01097

Q 47.6 Thu 15:30 a320

Stimulated decay and formation of antihydrogen atoms (arXiv:1912.03163) — •Tim Wolz[1], Chloé Malbrunot[1], Lilian Nowak[1], Daniel Comparat[2], and Mélissa Vieille-Grosjean[2] — [1]Physics Department, CERN, Genève 23, 1211, Switzerland — [2]Laboratoire Aimé Cotton, CNRS, Université Paris-Sud, ENS Paris Saclay, Université Paris-Saclay, 91405 Orsay, France

Antihydrogen atoms (Hbar) are routinely formed at the Antiproton Decelerator at CERN in a wide range of Rydberg states. However, precision measurements for stringent tests of the CPT theorem as well as first direct measurements of Earth's gravitational acceleration of antimatter require ground state (GS) atoms. Currently, experiments solely rely on spontaneous decay which so far only allowed for measurements in a neutral atom trap. We report on methods to stimulate the decay of the Rydberg atoms especially in the framework of a beam formation to extract the atoms into a field free region. We propose deexcitation schemes relying on E and B field mixing (applicable to a pulsed charge exchange Hbar production scheme) as well as THz and microwave mixing (applicable to a quasi continuous three body recombination Hbar production scheme). Both methods make use of a (visible) deexcitation laser. We obtain, in either case, close to unity ground state fractions within a few tens of microseconds. Combining such deexcitation methods with a stimulated radiative recombination allows for a direct formation of Hbar atoms in ground state. Finally, we report on first steps toward an experimental implementation of the proposed techniques.

Q 48: Quantum Information (Quantum Communication and Quantum Repeater) II

Time: Thursday 14:00–16:00 Location: e001

Group Report Q 48.1 Thu 14:00 e001

Quantum Readout of Physical Unclonable Keys for Authentication and Authenticated Communication — •Pepijn W. H. Pinkse — University of Twente, Enschede, The Netherlands

Authentication is essential to ensure trust in communication in modern society and will play an even more important role in automated networks. Symmetric authentication schemes rely on a shared secret, which does not scale well with the number of potential communication partners. Asymmetric authentication schemes rely on the combination of a public key and a private key. This scales better with the number of potential partners, but still requires a secret to be kept and stored in a secure way, which could be copied without the owner knowing. This is an important issue even in Quantum Key Distribution schemes that do not provide an intrinsic solution for the authentication of the communication partners.

In the past we have demonstrated the quantum-secure optical readout of a physical unclonable key (PUK) [1]. A PUK is a unique key which cannot be physically copied with existing or foreseeable technology. Recently, we have devised a communication scheme based on optical PUKs employing readout with shaped complex wavefronts of weak coherent light pulses [2].

In this talk I will give an overview of the state of the art, some insights in the hardness of copying and the possibilities to do readout over single-spatial modes.

[1] Goorden et al., Optica 1, 421 (2014). [2] Uppu et al., Quantum Sci. Tech. 4, 04501 (2019).

Q 48.2 Thu 14:30 e001

Quantum conference key agreement — •Gláucia Murta, Giacomo Carrara, Federico Grasselli, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine- Universität Düsseldorf, Universitätsstr. 1, D-40225 Düsseldorf, Germany

Conference key agreement is a cryptographic task in which several parties wish to establish a common key that is unknown to any eavesdropper. Protocols based on quantum resources allow to achieve unconditional security. Unconditionally secure conference key agreement can be established using several instances of bipartite quantum key distribution. However, multipartite quantum correlations bring the possibility of designing new protocols. In this talk we focus on conference key agreement protocols that make use of multipartite entangled states. We characterize the resources required to establish a secure conference key. We then focus on existing protocols and discuss their performance. Finally we move to a device-independent setup and discuss results towards protocols with higher rates.

Q 48.3 Thu 14:45 e001

Bell measurement using entangled telecom photons with ancilla qubits — •Nico Sieber, Matthias Bayerbach, Nico Hauser, Daniel Bhatti, and Stefanie Barz — Institute for Functional Matter and Quantum Technologies, University of Stuttgart

Photonic devices are key to a large range of quantum technologies, for example quantum communication and wider quantum networks. When transmitting quantum information over long distances, minimizing losses is crucial to any quantum protocols. Thus, the favourable wavelength is in the telecom regime 1550 nm). Many quantum protocols thus rely on pure and indistinguishable photons at this wavelength. Here we demonstrate the generation of entanglement in this wavelength regime using a parametric down-conversion photon pair source in a linear configuration which will be sent, together with ancilliary states, through a network of linear elements.

Q 48.4 Thu 15:00 e001

Quantum teleportation using highly coherent emission from telecom C-band quantum dots — •Tina Mueller[1], Matthew Anderson[1,2], Joanna Skiba-Szymanska[1], Andrey Krysa[3], Jan Huwer[1], Mark Stevenson[1], Jon Heffernan[4], David Ritchie[2], and Andrew Shields[1] — [1]208 Science Park, Milton Road, Cambridge CB4 0GZ, UK — [2]Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK — [3]EPSRC National Epitaxy Facility, University of Sheffield, Sheffield S1 3JD, UK — [4]Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield, S1 3JD, UK

Quantum network technologies rely on interference of indistinguishable photons, demanding sources of highly coherent single photons, with ideal wavelength around 1550 nm for fibre-based applications. Recently, emission of single and entangled photons from semiconductor sources in that band has been reported, but demonstration of sufficiently long coherence times has been outstanding. We show that InAs/InP quantum dots emitting in the telecom C-band can provide photons with coherence times exceeding 1 ns. These values enable near-optimal interference of quantum dot emission with a C-band laser qubit. Using entangled photons we further demonstrate teleportation of such qubits with a fidelity reaching 83.6(2.2)%.

Q 48.5 Thu 15:15 e001

A high bandwidth quantum network node with a single trapped ion in an ultraviolet fiber cavity — •Pascal Kobel[1], Moritz Breyer[1], Ralf Berner[1], Vidhya Sasidharan Nair[1], Konstantin Ott[2], Jakob Reichel[2], and Michael Köhl[1] — [1]Physikalisches Institut, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany — [2]Laboratoire Kastler-Brossel, ENS/UPMC-Paris 6/CNRS, F-75005 Paris, France

We investigate the integration of fiber cavities into ion traps for use in quantum networks. Since ions typically have their strongest dipole transition in the ultraviolet (UV), the extension of fiber cavities to work in the UV is important for high bandwidth networks. We present coupling of a single Ytterbium ion to a 260 μm long fiber cavity, which is resonant with the electric dipole transition at 370 nm. We achieve a coherent coupling rate of a single ion to the cavity of about $g/2\pi = 60$ MHz, which exceeds previous realizations by more than one order of magnitude. Using the Purcell effect, we demonstrate single photon generation and efficient extraction by pulsed ion excitation. Coherent manipulation of the hyperfine qubit enables us to investigate entanglement between the photon polarization and the spin state of the ion.

Q 48.6 Thu 15:30 e001

Performance Optimization Tools for Single-Photon Quantum Key Distribution — •Timm Kupko[1], Martin v. Helversen[1], Lucas Rickert[1], Jan-Hindrik Schulze[1], André Strittmatter[1,2], Manuel Gschrey[1], Sven Rodt[1], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Experimentelle Physik, Otto-von-Guericke Universität Magdeburg, 39106 Magdeburg, Germany

Solid-state quantum light sources have the potential to boost quantum communication [1,2]. Here, we report on tools to optimize the performance of quantum key distribution (QKD) implemented with single-photon sources (SPSs). We analyze the performance of a receiver module designed for polarization encoded QKD using deterministically-fabricated quantum dot SPSs. Exploiting two-dimensional temporal filtering and real-time security monitoring, we analyze the sifted key fraction, the quantum bit error ratio, and $g^{(2)}(0)$ expected in full implementations of the BB84 protocol as a function of the acceptance time-window. This routine enables us to choose optimal filter settings depending on the losses of the quantum channel [3]. Our findings are relevant for the development of QKD-secured communication networks based on quantum-light sources.

[1] T. Heindel et al., New J. Phys. 14, 083001 (2012)
[2] E. Waks et al., Phys. Rev. A **66**, 042315 (2002)
[3] T. Kupko et al., arXiv:1908.02672 (2019)

Q 48.7 Thu 15:45 e001

Storing single photons in a room temperature vapor cell — •Roberto Mottola[1], Gianni Buser[1], Chris Müller[2], Tim Kroh[2], Sven Ramelow[2], Oliver Benson[2], Philipp Treutlein[1], and Janik Wolters[1,3] — [1]Universität Basel, Schweiz — [2]HU Berlin — [3]DLR Institut für optische Sensorsysteme Berlin

Quantum memories are a key ingredient for the realization of quantum networks [1]. Furthermore, they allow the synchronization of probabilistic single photon sources significantly enhancing the generation rates of multiphoton states [2].

We implemented a broadband, optical quantum memory in hot Rb vapor with on-demand storage and retrieval [3]. With a bandwidth matched spontaneous parametric downconversion (SPDC) source, we can generate heralded single photons suited for storage with a heralding efficiency $\approx$ 50 % [4]. We report on our recent achievements in storing SPDC single photons with a linewidth of 230 MHz with an end-to-end efficiency $\eta_{e2e} = 1.3(1)$ % for a storage time of $T = 50$ ns. A signal to noise ratio of 1.9(2) and a memory lifetime $\tau = 380$ ns are achieved. The measurement of the second order autocorrelation of retrieved single photons results in $g^{(2)} = 0.91(3)$, showing that the non-classical properties of the stored light are maintained.

[1] N. Sangouard et al., *Rev. Mod. Phys.* **83**, 33 (2011).
[2] J. Nunn et al., *Phys. Rev. Lett.* **110**, 133601 (2013).
[3] J. Wolters, et al., *Phys. Rev. Lett.* **119**, 060502 (2017).
[4] R. Mottola et al., arXiv:1908.00590v2 (2019).

Q 49: Quantum gases (Miscellaneous)

Time: Thursday 14:00–16:00 Location: e214

Invited Talk Q 49.1 Thu 14:00 e214

New physical concepts: Fermionic Exchange Force and Bose-Einstein Force — •Christian Schilling — Arnold Sommerfeld Center for Theoretical Physics, LMU München

The particle-exchange symmetry has a strong influence on the behavior and the properties of systems of N identical particles. While fermionic occupation numbers are restricted according to Pauli's exclusion principle, $0 \leq n_k \leq 1$, bosonic occupation numbers can take arbitrary values $0 \leq n_k \leq N$. It is also a matter of fact, however, that occupation numbers in realistic systems of interacting fermions and bosons can never attain the maximal possible value, i.e., 1 and N, respectively. By resorting to one-particle reduced density matrix functional theory we provide an explanation for this: The gradient of the exact functional diverges repulsively whenever an occupation number n_k tends to attain the maximal value. In that sense we provide in particular a fundamental and quantitative explanation for the absence of complete Bose-Einstein condensation (as characterized by $n_k = N$) in nature. These new concepts are universal in the sense that the fermionic exchange force and the Bose-Einstein force are present in all systems regardless of the particle number N, the spatial dimensionality and the interaction potentials.

Q 49.2 Thu 14:30 e214

Measurement of identical particle entanglement and the influence of antisymmetrisation — •Jan Hendrik Becher[1], Enrico Sindici[2], Ralf Klemt[1], Philipp M. Preiss[1], Andrew J. Daley[2], and Selim Jochim[1] — [1]Physics Institute, Heidelberg University, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Department of Physics and SUPA, University of Strathclyde, Glasgow G4 0NG, UK

We explore the relationship between symmetrisation and entanglement through measurements on few particle systems in a multi-well potential. In particular, considering two or three trapped atoms, we measure and distinguish entanglement characterised in terms of spatial modes from genuine multipartite entanglement arising from two different physical origins: antisymmetrisation of the fermionic wavefunction and interaction between particles. We quantify this through the entanglement negativity of states, and the introduction of an antisymmetric negativity, which allows us to understand the role that symmetrisation plays in the measured entanglement properties.

Q 49.3 Thu 14:45 e214

Dynamics of a 3D Bose gas in an optical lattice driven by local particle loss — •Christopher Mink, Axel Pelster, and Michael Fleischhauer — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We study both the steady states and the dynamics of a weakly interacting Bose gas, which is confined by an optical lattice in one spatial dimension as well as an isotropic harmonic trap in the two transveral directions and with local particle loss. To this end we start from first principles and use coherent-state phase space methods in order to derive a Fokker-Planck description of the emerging Bose-Einstein condensates. Neglecting quantum fluctuations we determine the condensate wave functions at each lattice site approximately by using a suitable variational ansatz. We discuss the strengths of this approach and demonstrate the limits of its applicability. Finally, we take quantum fluctuations into account by reducing the dimension of the Fokker-Planck equation and study their impact on the time evolution of the system numerically. With this we aim at reproducing the experimental results of Ref. [1] concerning the refilling dynamics of an empty site without any free parameters.

[1] R. Labouvie, B. Santra, S. Heun, and H. Ott, Phys. Rev. Lett. **116**, 235302 (2016)

Q 49.4 Thu 15:00 e214

Observation of a non-equilibrium phase transition in the second order coherence of a Bose-Einstein condensate of photons — •Fahri Emre Ozturk[1], Tim Lappe[2], Göran Hellmann[1], Frank Vewinger[1], Julian schmitt[3], Jan Klaers[4], Hans Kroha[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]Physikalisches Institut and Bethe Center for Theoretical Physics, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [3]Present address:Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [4]Present address: Complex Photonic Systems (COPS), MESA+ Institute for Nanotechnology, University of Twente, 7522 NB Enschede, The Netherlands

Bose-Einstein condensates have been realized with cold atomic gases, exciton-polaritons and more recently with photons in dye-filled optical microcavities. In the latter system, grand canonical Bose-Einstein condensation has been demonstrated with enhanced statistical number fluctuations in the condensed state. Here we report on the observation of a transition between an oscillatory and a bi-exponential phase of the second order coherence of the condensate. The experiments are performed in a dye-filled optical microcavity at conditions very close to thermal equilibrium, with pumping and loss resulting in time-reversal symmetry breaking. The results show that photon Bose-Einstein condensates in a part of the phase diagram are separated by a phase transition from the non-equilibrium phenomenon of lasing.

Q 49.5 Thu 15:15 e214

Quantum simulation of a U(1) lattice gauge theory — Bing Yang[1], •Robert Ott[2], Hui Sun[1], Han-Yi Wang[1], Torsten V. Zache[2], Jad C. Halimeh[3,4], Zhen-Sheng Yuan[1], Philipp Hauke[3,4], and Jian-Wei Pan[1] — [1]Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Philosophenweg 16, 69120 Heidelberg — [3]Im Neuenheimer Feld 227, 69120 Heidelberg — [4]Via Sommarive 14, 38123 Povo (TN), Italy

The modern description of elementary particles is built on gauge theories. Such theories implement fundamental laws of physics by local constraints, such as Gauss's law in the interplay of charged matter and electromagnetic fields. Here, we demonstrate the quantum simulation of an extended U(1) lattice gauge theory, and experimentally quantify the faithfulness to Gauss's law. We use single-species bosonic atoms in alternating wells of a 71-site optical superlattice to realize charged matter and gauge fields, and experimentally benchmark the dynamics of their interaction by sweeping across a quantum phase transition. Enabled by new measurement techniques, we certify Gauss's law by extracting probabilities of locally gauge-invariant states from correlated boson occupations across three adjacent wells. Our results demonstrate that Gauss's law can be faithfully engineered in large-scale quantum simulators of gauge theories.

Q 49.6 Thu 15:30 e214

Non-Linear Multi-Component Excitations in a Spinor Bose-Einstein Condensate — •Stefan Lannig[1], Christian-Marcel Schmied[1], Maximilian Prüfer[1], Philipp Kunkel[1], Marc Robin Strohmaier[1], Helmut Strobel[1], Thomas Gasenzer[1], Panayotis G. Kevrekidis[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institute for Physics, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Department of Mathematics and Statistics, University of Massachusetts, Amherst, MA 01003-9305, USA

Far from equilibrium the presence or absence of non-linear excitations in a quasi-one-dimensional spinor Bose-Einstein condensate (BEC) leads to different universal scenarios in the effective long-wavelength properties of the system [1, 2]. To investigate this effect, we consider the basic scenario of only a few controlled excitations.

Here, we experimentally study such excitations in a quasi-one-dimensional spin-1 BEC of ^{87}Rb. Using an acousto-optical deflector we generate pairs of multi-component excitations in a controlled manner by local spin rotations and study their properties in the spatial degree of freedom and spin [3]. As these non-linear multi-component excitations exhibit long lifetimes we are able to observe their time evolution, and, in particular, collisions between them. We find that such interactions crucially depend on the internal spin structure of the excitations.

[1] Prüfer, M. et al., Nature **563**, 217 (2018)
[2] Schmied, C.-M. et al., Phys. Rev. A **99**, 033611 (2019)
[3] Kunkel, P. et al., Phys. Rev. Lett. **123**, 063603 (2019)

Q 49.7 Thu 15:45 e214

Realization of Bose-Einstein condensation in higher Bloch bands of the optical honeycomb lattice — •Tobias Klafka, Alexander Ilin, Julius Seeger, Phillip Gross, Klaus Sengstock, and Juliette Simonet — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Bose-Einstein condensates in higher Bloch bands of optical lattices immensely extend the possibilities for quantum simulation of solid-state models. Unconventional superfluids and new topological states of matter are expected to emerge by the interplay of spin and orbital degrees of freedom as well as the lattice symmetry.

We report on Bose-Einstein condensation in the second and forth band of a bipartite honeycomb lattice. Tuning the energy offset between the two sublattices allows a controlled transfer to higher bands. We have investigated the emergence of coherence for these metastable states as well as the interplay of band relaxation dynamics and condensation by tracing the dynamics in the Brillouin zones. Understanding these non-equilibrium processes constitutes an essential requirement for the stabilization of unconventional spinor condensates in higher bands.

Q 50: Ultra-cold atoms, ions, and BEC VI (joint session A/Q)

Time: Thursday 14:00–15:45 Location: f303

Invited Talk Q 50.1 Thu 14:00 f303

Dynamics of a mobile hole in a Hubbard antiferromagnet — •Martin Lebrat, Geoffrey Ji, Muqing Xu, Christie Chiu, and Markus Greiner — Harvard University, Cambridge, MA, USA

The interplay between spin and charge underlies much of the phenomena of the doped Hubbard model. Quantum simulation of the Hubbard model using quantum gas microscopy offers site-resolved readout and manipulation, enabling detailed exploration of the relationship between the two. We use this platform to explore spin and charge dynamics upon the delocalization of an initially-pinned hole dopant. We first prepare a two-component quantum gas of Lithium-6 loaded into a square optical lattice at half-filling and strong interactions, where the atoms exhibit antiferromagnetic spin ordering. During the loading process, we use a digital micromirror device to pin a localized hole dopant into the antiferromagnet. We then release the dopant and examine how it interacts with and scrambles the surrounding spin environment. The microscopic dynamics of dopants may provide further insight into the phases that appear in the doped Hubbard model.

Q 50.2 Thu 14:30 f303

Hubbard Parameters for Quasi-Two-Dimensional Optical Lattices — •Tobias Ilg and Hans Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, DE-70550 Stuttgart, Germany

We investigate a microscopic model of two particles interacting via a Feshbach resonance in a quasi-two-dimensional optical lattice. The transverse direction is confined by a harmonic trap, and in the quasi-two-dimensional regime we make the connection between the Hubbard parameter of a single band two-dimensional Hubbard model and the scattering length in three dimensions. Our procedure takes into account the proper renormalization of the low-energy scattering amplitude as well as contributions from all higher bands. We shows that in contrast to the three-dimensional case, higher bands always have an impact on the Hubbard parameter, even for deep optical lattices.

Q 50.3 Thu 14:45 f303

Three-dimensional time-reversal-invariant Hofstadter-Hubbard model — •Bernhard Irsigler[1], Jun-Hui Zheng[1,2], Fabian Grusdt[3,4], and Walter Hofstetter[1] — [1]Goethe-University Frankfurt, Germany — [2]NTNU, Trondheim, Norway — [3]MCQST, Munich, Germany — [4]LMU, Munich, Germany

We report on the three-dimensional time-reversal-invariant Hofstadter model with finite spin-orbit coupling. We introduce three numerical methods for characterizing the topological phases based on twisted boundary conditions, Wilson loops, as well as the local topological marker. Besides the weak and strong topological insulator phases we find a nodal line semimetal in the parameter regime between the two three-dimensional topological insulator phases. Using dynamical mean-field theory combined with the topological Hamiltonian approach we find stabilization of these three-dimensional topological states due to the Hubbard interaction. We study surface states which exhibit an asymmetry between left and right surface originating from the broken parity symmetry of the system. Our results set the stage for further research on inhomogeneous three-dimensional topological systems, proximity effects, topological Mott insulators and non-trivially linked nodal line semimetals.

Q 50.4 Thu 15:00 f303

Bilayer Fermi - Hubbard physics with a quantum gas microscope — •Sarah Hirthe[1], Joannis Koepsell[1], Dominik Bourgund[1], Jayadev Vijayan[1], Pimonpan Sompet[1], Guillaume Salomon[1], Immanuel Bloch[1,2], and Christian Gross[1,3] — [1]Max-Planck-Institute of Quantum Optics — [2]Ludwig-Maximilians Universität München — [3]Eberhard Karls Universität Tübingen

The bilayer Fermi-Hubbard model is of special interest for quantum simulation, as bilayered structures are prominent in materials such as the high-Tc superconducting cuprates. We have recently upgraded our Fermi gas microscope with a highly stable vertical superlattice, which now allows us full control over a strongly interacting fermionic bilayer system. We investigate the bilayer phase diagram by probing the Mott insulator to band insulator as well as the metal to band insulator transition. We confirm the expected transition point at an interlayer coupling of four times the intralayer coupling. Furthermore, making use of the full control over the lattice potential, we demonstrate a new technique based on topological charge pumping to reach single-site resolution of each layer. We benchmark the power of this technique by applying it to fully spin resolve a two-dimensional system. We find a strongly correlated system at temperatures consistent with the coldest temperatures reported in cold atoms.

Q 50.5 Thu 15:15 f303

Coherent control in a driven Fermi-Hubbard system — •Anne-Sophie Walter, Frederik Görg, Kilian Sandholzer, Joaquín Minguzzi, Konrad Viebahn, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, Switzerland

Coherent control is a widely applied technique in fields ranging from chemistry to ultracold atoms. It aims at steering quantum dynamics by controlling the relative phase between external light fields. In the context of Floquet engineering in optical lattices, where the system is periodically driven in time, the drive can resonantly couple to higher Bloch bands leading to atom loss. To overcome this problem we apply a coherent control scheme which would allow for a wider range of possible driving frequencies.

In our experiment, we periodically modulate the potential depth of our 3D optical lattice at a frequency that excites atoms to a higher band. We apply coherent control by tuning the phase of an additional drive at twice the fundamental frequency which destructively interferes with the first. Through this technique we preserve both the band population as well as the fraction of double occupancies for two orders of magnitude longer compared to the single-frequency case. We find this technique to be effective even at strong Hubbard interactions. Strikingly, the lifetime of spin correlations, which are highly susceptible to heating, is also improved by two orders of magnitude and comparable to the static value. This successful application of coherent control in a periodically driven many-body system opens new possibilities for Floquet engineering in the presence of strong interactions.

Q 50.6 Thu 15:30 f303

A single beam grating magneto optical trap on an atom chip — •Hendrik Heine[1], Alexander Kassner[2], Christoph Künzler[2], Marc C. Wurz[2], Waldemar Herr[1], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Mikroproduktionstechnik, Leibniz Universität Hannover

Matterwave interferometry with Bose Einstein Condensates (BEC) promises exciting prospects in inertial sensing and research on fundamental physics both on ground and in space. BECs can be created very efficiently by using an atom chip and compact realisations have already been shown. However for transportable or space applications, it is vital to reduce the complexity in order to lower size, weight and power demands of the device.

In this talk I will present a magneto optical trap and sub-Doppler cooling using only a single beam of light in combination with an optical grating on an atom chip. This reduces the complexity of the overall optical system and promises greater long-term stability. Finally, the atom chip allows for magnetic trapping and evaporative cooling by forced radio frequency evaporation towards a BEC.

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

Q 51: Quantum Optics IV

Time: Thursday 14:00–16:00 Location: f342

Q 51.1 Thu 14:00 f342

Lindbladian approximation beyond the ultra weak coupling assumption — •Tobias Becker, Ling-Na Wu, Daniel Vorberg, and André Eckardt — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden

Markovian master equations of Lindblad form for the description of open quantum systems have not only the advantage that they guarantee a completely positive trace preserving (CPT) evolution. They are also the starting point for efficient stochastic quantum trajectory simulations. For thermal environments, such Lindblad-type master equations are commonly derived by starting from the Redfield-equation obtained within Born-Markov approximation and by applying additionally also a rotating-wave (or secular) approximation. However, the latter requires ultra weak system-bath coupling, which is small compared to the level splitting in the system, a condition which is hard to achieve in large systems that approach a continuous spectrum in the thermodynamic limit. Here, we describe an alternative approximation to the Redfield equation, which also leads to a master equation of Lindblad form. This approximation does not require ultra weak system bath coupling, but rather sufficiently large temperatures. It, thus, works in regimes, where the secular approximation breaks down. We test our results using the example of an extended Hubbard chain coupled to two baths of different temperature.

Q 51.2 Thu 14:15 f342

Master equation for multilevel interference in a superradiant medium — •Aleksei Konovalov, Andreas Buchheit, and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

We derive a master equation for a superradiant medium which includes multilevel interference between the individual scatterers. The derivation relies on the Born-Markov approximation and implements the coarse graining formalism. The master equation fulfils the Lindblad form, the dynamics it predicts shows that the scattering properties are affected by the interplay between single-atom multilevel interference, multi-atom interference between identical transitions, and multi-atom interference between different electronic transitions with parallel dipoles. This formalism is then applied to determine the excitation spectrum of two atoms using the parameters of the Hydrogen transitions $2S_{1/2} \rightarrow 4P_{1/2}$ and $2S_{1/2} \rightarrow 4P_{3/2}$. The distortion of the signal due to the interplay of multilevel and multi-atom interference is discussed as a function of the interatomic distance. These results are relevant for the realization of atomic clocks using cold atomic ensembles.

Q 51.3 Thu 14:30 f342

Dynamical detection of dipole-dipole interactions in dilute atomic gases — •Benedikt Ames, Edoardo Carnio, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Recent experiments have identified signatures of the dipole-dipole interaction in extremely dilute, thermal atomic vapors via fluorescence signals excited by ultrashort, phase-modulated laser pulses [1]. The nonlinear spectroscopic technique allows to extract spectral features stemming from collective effects from an intense single-scattering background, down to the lowest experimentally accessible densities of $\sim 10^7\,\mathrm{cm}^{-3}$.

To provide quantitative, analytical expressions for the fluorescence signals, we use an open quantum system treatment which was previously employed to investigate coherent backscattering of light by cold atoms [2]. By adapting it to time-dependent driving, we obtain a model which is non-perturbative in the atom-laser interaction and admits a series expansion with respect to the weak inter-atomic coupling as mediated by the exchange of (transverse) photons. In terms of those single- and double-scattering contributions to the scattering series which survive the average over random atomic configurations, we interpret the lineshapes and relative strength of single- and double-quantum coherence signals.

[1] L. Bruder et al., Phys. Chem. Chem. Phys. **21**, 2276–2282 (2019)
[2] V. Shatokhin, C. Müller, A. Buchleitner, Phys. Rev. A **73**, 063813 (2006)

Q 51.4 Thu 14:45 f342

Quantum illumination for remote target detection — •Giacomo Sorelli[1,2], Nicolas Treps[2], Frédéric Grosshans[3], Claude Fabre[2], and Fabrice Boust[1] — [1]Département ElectroMagnétisme et Radar, Onera - Paliseau - France — [2]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France - Paris - France — [3]LIP6, Sorbonne Université, CNRS - Paris - France

Entanglement revealed to be a fundamental resource to provide sensing performance beyond those allowed by classical physics. It is therefore natural to explore its potential to improve radar technology. The first attempt in this direction is represented by quantum illumination [1]: an entanglement-based protocol to detect a low-reflectivity target immersed in high thermal background. The most astonishing characteristic of this protocol is that, under specific energy constraints, it provides a quantum advantage, even though noise and losses completely destroy the initial entanglement.

In this talk we will review the continuous variable version [2] of the quantum illumination protocol. In particular, by using figures of merit typical of the classical radar literature, we will evaluate its performances in realistic radar and lidar scenarios. We will show that the regime where the standard quantum illumination protocol provide an advantage over classical radar is of little use in such realistic settings and discuss how one could overcome this limitation.

[1] S. Lloyd, Science 321, 5895, 1463-1465 (2008)
[2] Tan et al., Phys. Rev. Lett. 101, 253601 (2008)

Q 51.5 Thu 15:00 f342

Optimizing spontaneous parametric down-conversion sources for boson sampling — •Reinier van der Meer[1], Jelmer J. Renema[1], Benjamin Brecht[2], Christine Silberhorn[2], and Pepijn W. H. Pinkse[1] — [1]University of Twente, Enschede, The Netherlands — [2]Paderborn University, Paderborn, Germany

The next milestone in photonic quantum information processing is to demonstrate an optical experiment at which the quantum device outperforms any classical computer. This can be achieved by sending single photons through a passive linear-optical network. However, this requires the generation of many identical single photons, which is challenging to realize. Spectral impurity reduces the visibility of quantum interference of the photons, which can be mitigated by filtering at the cost of optical losses. Unfortunately, these losses are also detrimental to quantum interference.

We recently demonstrated how to analyze the role of imperfections in multiphoton interference experiments [1]. We now apply these results to the problem of constructing single-photon sources. In this work we show that an optimum exists where we can outperform a classical computer, using off-the-shelf parametric down-conversion photon sources. These results show that demonstrating a quantum advantage using photonics is difficult, but possible.

[1] J.J. Renema et al., arXiv: 1809.01953 (2018)

Q 51.6 Thu 15:15 f342

Correlated photon-pair emission from a cw-pumped Fabry-Perot microcavity — •Thorsten F. Langerfeld, Felix Rönchen, Hendrik M. Meyer, and Michael Köhl — Physikalisches Institut, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany

The generation of correlated photons is an important milestone in fundamental test of quantum mechanics and in the quest to interconnect remote quantum systems with the goal of creating quantum networks. For the latter, a tunable photon pair source, which can be tailored to the physical properties of the network nodes is desirable. For that purpose, we study a dispersion-compensated high-finesse optical Fabry-Perot microcavity under high-intensity cw pumping. The Kerr non-linearity in the optical coatings causes a spontaneous four-wave mixing process, triggered by vacuum fluctuations of the unoccupied cavity modes. Thus time-correlated photon pairs are emitted, which are shifted in frequency by ± 1 free spectral range relative to the pump frequency. The ease of the experimental setup and the principal tunability of the wavelengths and bandwidths of the created photon pair make the scheme an attractive candidate for a photon-pair source with application in hybrid quantum systems in which wavelength has to be bridged between dissimilar systems. Furthermore, by filling the cavity with a synthetic silicon oil the optical non-linearity is extended over the entire cavity length which increased the pair correlation rate by a factor of more than 10^3 and improved the coincidence to accidental ratio by a factor of 1.7.

Q 51.7 Thu 15:30 f342

Quantum Feedback, self-stimulation and Fock State Generation — •Melanie Engelkemeier[1], Ish Dhand[2], Evan Meyer-Scott[1], Jan Sperling[1], Sonja Barkhofen[1], Benjamin Brecht[1], Martin Plenio[2], and Christine Silberhorn[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]Universität Ulm, Institut für Theoretische Physik, Helmholtzstraße 16, D-89081 Ulm

The generation of higher-order Fock states is important for several physical applications, such as fundamental studies of physics and quantum metrology. Usually, the means of choice to generate heralded higher-order Fock states is a dispersion-engineered parametric down conversion (PDC) process. These processes feature a high overall brightness, however the probability to generate specific higher-order Fock states decreases with increasing state size; large states are generated only at low rates. To overcome this challenge, we utilize a time-multiplexed quantum feedback, which introduces self-stimulation in the PDC process. This leads to a successive build up of higher order Fock states due to a coherent addition of photons. Therefore, within this setup, it is possible to generate higher-order Fock states with higher rates compared to a single PDC source. In this talk, we report on the current status of this project.

Q 51.8 Thu 15:45 f342

Second Harmonic Generation at Cryogenic Temperatures in Lithium Niobate Waveguides — •Nina Amelie Lange[1], Moritz Bartnick[1], Jan Philipp Höpker[1], Frederik Thiele[1], Raimund Ricken[2], Viktor Quiring[2], Christof Eigner[2], Harald Herrmann[2], Christine Silberhorn[2], and Tim Bartley[1] — [1]Mesoskopische Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Integrierte Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Waveguides in lithium niobate have shown extensive functionality in quantum photonics. Their high second-order nonlinearity and electro-optic properties make them ideal for nonlinear processes and active manipulation of quantum optical states. These properties are well-known under ambient conditions; however, to be compatible with other photonic technologies such as single photon emitters and superconducting detectors, optimisation at cryogenic temperatures is required. We demonstrate second harmonic generation (SHG) down to a temperature of 4K, using a robust fibre-pigtailing procedure, a narrowband tuneable pump laser and a closed-cycle cryostat. We analyse the role of the temperature change on the phasematched wavelength, and investigate various dynamics across different timescales, which indicate the appearance of pyroelectric fields.

Q 52: Cold Molecules II (joint session Q/MO)

Time: Thursday 14:00–15:45 Location: f442

Invited Talk Q 52.1 Thu 14:00 f442
Long-range interactions between polar molecules and Rydberg atoms — •Martin Zeppenfeld — MPI für Quantenoptik, Hans-Kopfermann Str. 1, 85748 Garching

Due to large dipole moments in polar molecules and huge dipole moments in Rydberg atoms, strong interactions between polar molecules and Rydberg atoms persist for separations beyond $1\,\mu$m. This provides exciting opportunities in quantum science, with applications such as cooling of internal or motional molecular degrees of freedom, nondestructive molecule detection, and quantum information processing.

In my talk, I will provide an overview of these opportunities and present my work on realizing such ideas experimentally. In particularly, we have investigated Förster resonant energy transfer between molecules and Rydberg atoms at room temperature in the past, observing huge interaction cross sections and electric-field-controlled collisions. Currently we are setting up a new experiment to investigate interactions between cold molecules and Rydberg atoms, providing many new opportunities.

Q 52.2 Thu 14:30 f442
Heteronuclear long-range Rydberg molecules — •Michael Peper[1] and Johannes Deiglmayr[2] — [1]Laboratory of Physical Chemistry, ETH Zürich — [2]Felix-Bloch Institut, University of Leipzig

The binding of long-range Rydberg molecules is based on the low-energy scattering of an Rydberg atom's electron off a neutral ground-state atom within its orbit. Improving the quantitative understanding of this binding mechanism thus carries the potential to extract electron-atom-scattering potentials, important quantities to benchmark *ab-initio* atomic structure calculations [1], from photoassociation spectra of long-range Rydberg molecules. Current theoretical models are, however, challenged by the necessity to accurately model the scattering interaction while including all relevant spin couplings, such as the hyperfine interaction [2].

We propose to rigourously test the modelling of long-range Rydberg molecules by isoelectronic substitution, *i.e.*, by systematically varying isotopic variant and chemical species of both Rydberg and ground-state atom. To this end we have completed the construction of a dual-species ultracold atom experiment, which allows for simultaneous trapping of ultracold cesium and potassium atoms. We will present our current progress towards performing photoassociation spectroscopy of homo- and heteronuclear long-range Rydberg molecules in this setup.

[1] H. Saßmannshausen, F. Merkt, and J. Deiglmayr, PRL 114, 133201 (2015); F. Engel *et al.*, PRL 123, 073003 (2019); J.L. MacLennan, Y.-J. Chen, and G. Raithel, PRA 99, 033407 (2019) [2] C. Fey *et al.*, New J. Phys. 17, 055010 (2015)

Q 52.3 Thu 14:45 f442
Stability of quantum degenerate Fermi gases of tilted polar molecules — •Vladimir Veljić[1], Axel Pelster[2], and Antun Balaž[1] — [1]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

A recent experimental realization of quantum degenerate gas of ^{40}K^{87}Rb molecules opens up prospects of exploring strongly dipolar Fermi gases and many-body phenomena arising in that regime [1]. Here we derive a mean-field variational approach based on the Wigner function for the description of ground-state properties of such systems [2,3]. We show that the stability of dipolar fermions in a general harmonic trap is universal as it only depends on the trap aspect ratios and the dipoles orientation. We calculate the species-independent stability diagram and the deformation of the Fermi surface (FS) for polarized molecules, whose electric dipoles are oriented along a preferential direction. Compared to atomic magnetic species [2], the stability of a molecular electric system turns out to strongly depend on its geometry and the FS deformation significantly increases [3]. We also show that tuning the trap frequencies appropriately reduces the 3D sytem to a quasi-2D system of either a pancake- or a cigar-shaped gas cloud, which turn out to have smaller stability regions.

[1] L. De Marco et al., Science **363**, 853 (2019)
[2] V. Veljić et al., New J. Phys. **20**, 093016 (2018)
[3] V. Veljić et al., Phys. Rev. Res. **1**, 012009 (2019)

Q 52.4 Thu 15:00 f442
Progress on Zeeman slowing of CaF — •Mariia Stepanova, Paul Kaebert, Timo Poll, Maurice Petzold, Supeng Xu, Mirco Siercke, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Experiments with ultracold molecules promise to have a large impact on many fields of physics such as quantum simulations and computation, metrology and ultracold chemistry. Due to the complex energy level structure of molecules, direct laser cooling yields a relatively low number of particles that can be trapped. In this talk I will present a novel method of direct slowing of molecules, reminiscent of Zeeman slowing of atoms, which promises a significant increase in flux of slow molecules. I will show data from a proof-of-principle experiment using the D1-line of 39K, demonstrating the efficiency of the method. Comparing our proof-of-principle results shows a flux and slowing efficiency comparable to traditional D2-line Zeeman slowing, and a factor of ~20 increase in flux below 35m/s compared to white-light slowing. I will also highlight the newest developments in our experiment such as our efforts on implementing a chemical cell for molecule production in reaction of ablated Ca and SF6 gas. This will be followed up by our latest results in measurement of the CaF hyperfine structure as well as the Zeeman splitting in CaF energy levels at high magnetic fields.

Q 52.5 Thu 15:15 f442
Towards Direct Laser Cooling of Barium Monofluoride — •Ralf Albrecht, Marian Rockenhäuser, and Tim Langen — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

We report on the progress of our experiment for the direct laser cooling and trapping of barium monofluoride molecules. Laser cooling of molecules had long been considered impossible due to their complex vibrational and rotational level structure. However, beneficial Franck-Condon factors and selection rules allow for optical cycling in many molecular species, including barium monofluoride. Hot molecules are generated through laser ablation of a pressed pellet inside a cold cell and precooled by collisions with a cold buffer gas of helium atoms. The thermalized gas mixture exits the cell through a few-millimeter-sized aperture and enters a high vacuum region as a cold and intense beam. A careful characterization of this beam and demonstration of optical cycling is presented in [1], which paves the way for the implementation of transversal laser cooling of the beam. The current status of this effort will be presented.

[1]R.Albrecht et. al., arXiv: 1906.08798 (2019)

Q 52.6 Thu 15:30 f442
Manipulation of molecular hydrogen in a Rydberg-Stark state on a chip to study cold collisions — •Katharina Höveler[1], Johannes Deiglmayr[2], Josef Agner[1], Hansjürg Schmutz[1], and Frédéric Merkt[1] — [1]Laboratorium für Physikalische Chemie, ETH Zürich, 8093 Zurich, Switzerland — [2]Felix-Bloch Institut, Universität Leipzig, Linnéstraße 5, 04103 Leipzig, Germany

The exothermic, barrierless $H_2^+ + H_2 \rightarrow H_3^+ + H$ reaction has been studied in the collision-energy range $E_{\rm coll}/k_{\rm b} = 0.3 - 50\,$K. To reach such low collision energies, we use a merged-beam approach and substitute the H_2^+ reactants by the ionic cores of H_2 molecules in high-n Rydberg-Stark states. The Rydberg electron does not influence the reaction but shields the ion from heating by space-charge effects and stray electric fields. A curved surface-electrode device is used to deflect a supersonic beam of H_2 molecules excited to high-n Rydberg-Stark states and to merge it with a supersonic beam containing ground-state H_2 molecules. The collision energy is tuned by varying the temperature of the valve generating the H_2 ground-state beam for selected velocities of the deflected H_2 beam. The reaction cross section is found to follow the classical Langevin capture model down to $E_{\mathrm{coll}}/k_{\mathrm{b}} = 5\,\mathrm{K}$. At lower temperatures, a deviation is observed and attributed to ion-quadrupole long-range interactions. An expected different cross section for a pure para H_2(J=0) neutral reactant will be tested. Investigation of the reactions $H_2^+ + D_2$ and $H_2^+ +$HD enables us to distinguish between charge transfer, D or H atom transfer and H^+ ion transfer and to determine the ratio of the two competing reaction channels.

Q 53: SYCM: Contributed posters for the Symposium Hot topics in cold molecules: From laser cooling to quantum resonances

Time: Thursday 16:30–18:30 Location: Empore Lichthof

Q 53.1 Thu 16:30 Empore Lichthof

Single-source merged-beam experiment for the study of reactive collisions — •Marco van den Beld Serrano, Frank Stienkemeier, and Katrin Dulitz — University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg i. Br., Germany

We present an original merged-beam method for studying reactive collisions between two atomic or molecular species by the use of two gas pulses emerging from a single supersonic beam source. Our approach, which relies on the laser cooling and deceleration of a laser-coolable species inside a Zeeman slower, can be used for a wide range of scattering studies at thermal and at cold collision energies. A possible experimental implementation of the proposed method is outlined for autoionizing collisions between helium atoms in the metastable triplet state and a second, atomic or molecular species. Using numerical trajectory calculations, we provide estimates of the expected efficiency, the collision-energy range and the energy resolution of the approach. In addition to that, we have experimentally tested the feasibility of such an experiment by producing two gas pulses at very short time intervals, and the results of these measurements are detailed as well.

Q 53.2 Thu 16:30 Empore Lichthof

A buffer gas beam of AlF molecules and optical cycling — •Simon Hofsäss[1], Maximilian Doppelbauer[1], Sebastian Kray[1], Jesùs Pérez-Ríos[1], Boris Sartakov[2], Gerard Meijer[1], and Stefan Truppe[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]General Physics Institute, Russian Academy of Sciences, Moscow, Russia

We have recently identified the aluminium monofluoride (AlF) molecule as an excellent candidate for laser cooling and trapping at high densities and measured the detailed energy level structure of the electronic states relevant for these processes[1].

The first excited singlet state lifetime of 1.9 ns and the large photon recoil allow exerting a large cooling force to slow the molecules. The hyperfine structure in the excited state of the main cooling transition covers about 500 MHz, which allows slowing without chirping the laser frequency. The short excited state lifetime leads also to an exceptionally large capture velocity of a magneto optical trap, which is only limited by the available laser power in the UV.

Here we present the characterization of a cryogenic buffer gas molecular beam of AlF that will be used to load a magneto optical trap (MOT). Absorption and laser-induced fluorescence spectroscopy are used to determine the molecular flux. The velocity distribution is measured by combining optical pumping with a long time-of-flight. We investigate optical cycling and compare the measurements to a theoretical model.

[1] Truppe et al., Phys. Rev. A 100, 052513 (2019)

Q 53.3 Thu 16:30 Empore Lichthof

High-resolution optical spectroscopy of the $a^3\Pi$ and $b^3\Sigma^+$ states in aluminum monofluoride — •Maximilian Doppelbauer[1], Silvio Marx[1], Nicole Walter[1], Christian Schewe[1], Simon Hofsäss[1], Sebastian Kray[1], Boris Sartakov[2], Jesús Pérez-Ríos[1], Stefan Truppe[1], and Gerard Meijer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]General Physics Institute, Russian Academy of Sciences, Vavilovstreet 38, 119991 Moscow, Russia

Characterization of the triplet states of aluminum monofluoride (AlF) molecule is useful for laser cooling and trapping experiments[1].
The $b^3\Sigma^+$ - $a^3\Pi$ transition can be used for optical pumping, parity-selective detection of hyperfine levels in the $a^3\Pi$ state, and is a candidate for a triplet magneto-optical trap. The $A^1\Pi$ - $a^3\Pi$ transition is a possible loss channel for laser cooling on the $A^1\Pi$ - $X^1\Sigma^+$ transition.
We present the results of spectroscopic investigations involving the $a^3\Pi$ and $b^3\Sigma^+$ states and discuss their relevance for laser cooling. Spectroscopic constants are determined to high precision. This makes AlF an ideal benchmark molecule for quantum chemical calculations.

[1] Truppe et al., Phys. Rev. A 100, 052513 (2019)

Q 53.4 Thu 16:30 Empore Lichthof

Feshbach resonances in half-collisions between para/ortho H_2^+ and He — •Karl P. Horn[1], Daniel M. Reich[1,2], Arthur Christianen[3], Gerrit C. Groenenboom[3], Ad van der Avoird[3], Prerna Paliwal[4], Yuval Shagam[4], Nabanita Deb[4], Edvardas Narevicius[4], and Christiane P. Koch[1,2] — [1]Theoretical Physics, Universität Kassel, Germany — [2]Theoretical Physics, Freie Universität Berlin, Germany — [3]Theoretical Chemistry, IMM, Radboud University, Nijmegen, Netherlands — [4]Department of Chemical Physics, Weizmann Institute of Science, Rehovot, Israel

Imaging the final states of cold He-H_2^+ half-collisions reveals significant differences in the rotational distributions when using either para or ortho H_2^+ as a collision partner. We provide an explanation of the observed disparity in terms of the dominating influence of Feshbach resonances in the vibrationally excited states of the two spin isomers. To this end, we numerically simulate the half-collision process, utilising a state of the art potential[1] and full coupled channels calculations[2]. We substantiate our analysis by studying the difference in behaviour under interchange of either one or both hydrogen atoms with deuterium.

[1] M. Meuwly et al., Phys. Chem. Chem. Phys., 2019,21, 24976-24983
[2] S. N. Vogels et al., Science, 350. 787-790 (2015)

Q 53.5 Thu 16:30 Empore Lichthof

Designing a microwave trap for ultracold polar molecules — •Maximilian Löw, Martin Ibrügger, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Ultracold polar molecules are promising candidates for many different applications because of their rich internal structure and long-range dipole-dipole interactions. Optoelectrical Sisyphus cooling provides a high number of molecules at sub-millikelvin temperatures as we demonstrated with formaldehyde (H_2CO) in the past [1]. However, the electric trap used in the experiment prevents us from reaching high phase-space densities due to its large volume.

For this reason, we are designing a microwave trap as the next stage in our experiment. Working at a frequency of 50 GHz it acts as a red-detuned dipole trap on the rotational transition $|J,K_a,K_c\rangle = |211\rangle \leftarrow |110\rangle$ of formaldehyde. We present our progress in developing a high-finesse open mm-wave resonator to achieve trap depths of several mK with reasonable input power while maintaining optical access. We also show that we can prepare cooled formaldehyde in its ortho rotational ground-state $|110\rangle$. The microwave trap will enable us to further reduce the molecule temperature using evaporative or sympathetic cooling and allows us to aim for the regime of quantum degeneracy.

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

Q 53.6 Thu 16:30 Empore Lichthof

A new experimental setup to investigate cold molecule-Rydberg atom interactions — •Shreyas Gulhane and Martin Zeppenfeld — Max-Planck-Institut fuer Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Due to their large electric dipole moments, interactions between polar molecules and Rydberg atoms extend over large distances, allowing for applications in quantum science. In the past, we have investigated such interactions at room temperature, allowing the observation and investigation of Förster resonant energy transfer between these two systems [1].

Extending this work to cold molecules and cold Rydberg atoms provides new opportunities. In this contribution, we present the experimental setup. Slow molecules produced by velocity filtering via a quadrupole electric guide interact with Rydberg atoms excited from cold atoms inside a magneto-optical trap (MOT). We present the laser system for the MOT, a 780nm tappered amplifier diode laser locked to a rubidium vapor cell. This is combined with a 480nm frequency doubled diode laser for two-photon excitation of rubidium Rydberg states. In addition, we present our vacuum setup. This includes in-vacuum MOT coils and a carefully designed electrode arrangement for precise electric field control. [1]. F. Jarisch *et al.*, New J. Phys. **20**, 113044 (2018).

Q 54: Posters: Quantum Optics and Photonics IV

Time: Thursday 16:30–18:30 Location: Empore Lichthof

Q 54.1 Thu 16:30 Empore Lichthof

Towards the production of groundstate RbYb — Tobias Franzen, •Bastian Pollklesener, Christian Sillus, and Axel Görlitz — Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf

Ultracold dipolar molecules constitute a promising system for the investigation of topics like ultracold chemistry, novel interactions in quantum gases, precision measurements and quantum information.

Here we report on first experiments in our apparatus for the production of ultracold RbYb molecules. This setup constitutes an improvement of our old apparatus, where the interactions in RbYb and possible routes to molecule production have already been studied extensively [1,2]. In the new setup a major goal is the efficient production of ground state RbYb molecules.

We employ optical tweezers to transport individually cooled samples of Rb and Yb from their separate production chambers to a dedicated science chamber. Here we start to study interspecies interactions of different isotopes by overlapping crossed optical dipole traps. We report of first results of implementing a 3D lattice and using photoassociation spectroscopy on the way towards groundstate molecules.

[1] M. Borkowski et al., PRA 88, 052708 (2013)
[2] C. Bruni et al., PRA 94, 022503 (2016)

Q 54.2 Thu 16:30 Empore Lichthof

Effects of multiple lattices on atomic light-pulse diffraction — •Jens Jenewein[1], Sabrina Hartmann[1], Enno Giese[1], Albert Roura[1,2], Wolfgang P. Schleich[1,2], and and the QUANTUS Team[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Söflinger Str. 100, D-89077 Ulm, Germany

We study in detail the differences between Raman and Bragg diffraction for different regimes in a retro-reflective geometry [1]. Moreover, we demonstrate the transition between double and single diffraction for an increasing Doppler detuning. Besides the intrinsic limitations of the efficiency of a double-Bragg mirror pulse, imperfections in the orthogonality of the polarizations pose an even more important problem in large-momentum-transfer atom interferometry, as found in related experiments by the QUANTUS project. In order to circumvent these difficulties and to enhance the efficiency, we provide an alternative diffraction technique for mirrors based on standing waves which can be understood as a second-order single-Bragg pulse and demonstrate the robustness against polarization imperfections.

The QUANTUS and BECCAL projects are supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50WM1956 and 50WP1705.

[1] S. Hartmann, J. Jenewein et al., arXiv:1911.12169 [quant-ph]

Q 54.3 Thu 16:30 Empore Lichthof

From idealized to *realistic* atomic beam splitters - theoretical studies in 3D — •Antje Neumann and Reinhold Walser — Technische Universität Darmstadt, Germany

We analyze the response and aberrations of atomic beam splitters with spatio-temporal laser beam envelopes in three dimensions.

Atomic beam splitters are a central component of matter-wave interferometers, which provide the opportunity of high-precision rotation and acceleration sensing. Therefore, ultracold atoms are the ultimate quantum sensors. Potential applications range from tests of fundamental physics to inertial navigation. In the QUANTUS (Quantum Gases in Microgravity) free-fall experiments atom interferometry is the central method as well [1].

Like optical systems matter-wave devices require exact specifications and ubiquitous imperfections need to be quantified. Therefore, we study the performance of 3D atomic beam splitters in the velocity selective quasi Bragg configuration numerically as well as analytically, finally confirmed by experimental data [2]. We characterize the non-ideal behavior due to spatial variations of the laser beam profiles and wave front curvatures, regarding realistic Gaussian laser beams instead of ideal plane waves. Especially, we study the effect of slightly decentered and tilted lasers. Different temporal pulse shapes are considered.

This work is supported by the German Aeronautics and Space Administration (DLR) through grant 50 WM 1957.

[1] D. Becker et al., Nature 562, 391-395 (2018)
[2] M. Gebbe, Universität Bremen, Zarm, private communication.

Q 54.4 Thu 16:30 Empore Lichthof

On chip electron guiding — •Robert Zimmermann, Michael Seidling, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

The current status of beam guiding experiments based on to microstructured chips is reported.

Q 54.5 Thu 16:30 Empore Lichthof

Collimation of atomic ensembles in space — •Annie Pichery[1,2], Waldemar Herr[1], Matthias Meister[3], Patrick Boegel[3], Wolfgang P. Schleich[3], Ernst M. Rasel[1], Eric Charron[2], Naceur Gaaloul[1], and Nicholas P. Bigelow[4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, France — [3]Institut für Quantenphysik, Universität Ulm, Germany — [4]University of Rochester, New York, USA

Ensembles of cold atoms behave as matter-waves and are routinely used as input states for atom interferometers. The free expansion and the inherent atomic density drop make the signal detection difficult. By analogy with light, it is possible to collimate the clouds with atomic lenses, using the delta-kick collimation technique. In this contribution, we study a protocol for controlling the expansion of an atomic cloud applied to experiments in the NASA Cold Atom Laboratory (CAL) on board of the International Space Station. Such clouds collimated with the delta-kick technique could be observed over long periods of almost 400 ms. Other important techniques towards the preparation of atomic sources for precision atom interferometry in space are reported.

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. 50WM1861/2, and by *Niedersächsisches Vorab* through the QUANOMET initiative-project QT3, and financial support from NASA through CUAS RSAs including 1585910.

Q 54.6 Thu 16:30 Empore Lichthof

Spatial coherence properties of laser-triggered electron pulses towards higher currents — •Stefan Meier and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Tungsten needle tips represent well-suited electron sources for various applications, like electron microscopy or holography. In cold field emission, these tips provide a highly coherent electron beam, a key parameter for any electron-optical application. When ultrashort femtosecond laser pulses are focused on the tip, the electron emission can occur on timescales down to a few femtoseconds, leading to an ultrafast pulsed electron source. In recent experiments, we could show that the pulsed electron emission is spatially as coherent as cold field emission from the same tip [1]. Usually, femtosecond laser-triggered emission currents are below one electron per laser pulse to avoid electron-electron interaction within the small emission area and time. In this work, we investigate the properties of the spatial coherence towards one electron per pulse and show the current progress.

[1] S. Meier *et al.*, Appl. Phys. Lett. **113**, 143101 (2018).

Q 54.7 Thu 16:30 Empore Lichthof

T^3-interferometry — •Matthias Zimmermann[1], Maxim A. Efremov[1,2], Omer Amit[3], Frank A. Narducci[4], Wolfgang P. Schleich[1,2], and Ron Folman[3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [3]Department of Physics, Ben-Gurion University of the Negev, Be'er Sheva, Israel — [4]Department of Physics, Naval Postgraduate School, Monterey, USA

By exploiting the Kennard phase [1], we have proposed an atom interferometer [2] probing a linear potential and having a phase shift that scales as T^3, in contrast to conventional atom interferometers in the Mach-Zehnder configuration with a phase scaling as T^2, where T denotes the total interferometer time [3]. In this scheme we make use of two magnetic sensitive atomic states $|1\rangle$ and $|2\rangle$ leading to respective state-dependent accelerations a_1 and a_2 when the atom is exposed to a magnetic field gradient.

We present our unique Stern-Gerlach interferometer that enabled the successful observation of the cubic phase scaling [4]. As our device utilizes magnetic field gradients instead of light pulses for the beam-splitting process, it may serve as a unique probe for the study of surface properties.

[1] G. Rozenman et al., Phys. Rev. Lett. **122**, 124302 (2019)
[2] M. Zimmermann et al., Appl. Phys. B **123**, 102 (2017)
[3] M. Zimmermann et al., New J. Phys. **21**, 073031 (2019)
[4] O. Amit et al., Phys. Rev. Lett. **123**, 083601 (2019)

Q 54.8 Thu 16:30 Empore Lichthof

Large-Momentum-Transfer Atom Optics from a Floquet-Bloch viewpoint — •Eric P. Glasbrenner[1], Alexander Friedrich[1], Enno Giese[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), D-89077 Ulm, Söflinger Str. 100, Germany

Atom interferometers have evolved into high-precision instruments and are used nowadays in numerous applications as gravimeters, rotation sensors and in general inertial sensing tasks. The development rapidly moves towards compact setups aimed at the commercialization of atom interferometers. For such applications, both high precision and sensitivity are essential. One technique to increase the sensitivity is to use Large-Momentum-Transfer (LMT) methods such as double Bragg diffraction, sequential pulses or Bloch oscillations. In this contribution we propose a semi-analytical approach towards the description of light-pulse beam splitters and mirrors as well as Bloch oscillations in a unified framework. Specifically, we develop a Floquet-Bloch theory to model diffraction as well as Bloch oscillations which allows us to discuss e.g. the effects of parasitic lattices caused by imperfect polarization.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956.

Q 54.9 Thu 16:30 Empore Lichthof

State- and branch-dependent atom interferometry — •Enno Giese[1] and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, D-89077 Ulm, Germany

Light-pulse atom interferometry has evolved into a versatile and powerful tool for high-precision measurements of inertial forces. Whereas this sensitivity relies on the external degree of freedom, the internal structure of atoms gives another degree of freedom that makes them susceptible to relativistic effects [1,2]. In such a framework, the light-matter interaction takes place locally on each branch of the interferometer, making a branch-dependent formalism [3] a convenient and essential tool for the description of atom interferometers. Since the exact diffraction mechanism [4] as well as the specific geometry [3] determine the proper-time difference between the two branches, branch-dependent diffraction will have a similar effect. In our contribution we discuss atom interferometry from a branch-dependent perspective as well as the influence of different internal states and transitions.

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[1] arXiv:1810.06744 (2018)
[2] Sci. Adv. **5**, eaax8966 (2019)
[3] New J. Phys. **16**, 123012 (2014)
[4] Phys. Rev. A **99**, 013627 (2019)

Q 54.10 Thu 16:30 Empore Lichthof

Gravitational redshift in atomic clocks and atom interferometers — •Fabio Di Pumpo[1], Christian Ufrecht[1], Alexander Friedrich[1], Albert Roura[2], Wolfgang P. Schleich[1,2], and Enno Giese[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Söflinger Straße 100, D-89077 Ulm

The question of which atom-interferometer geometries can be used to test the gravitational redshift is at the center of a long-standing debate. We compare in this contribution classical redshift tests through the synchronization of two atomic clocks with the measurement results found in atom interferometers relying on i) quantum clock interference [1] or ii) internal state transitions during the interferometer [2]. For this purpose, we introduce a dilaton model which consistently parametrizes violations of the Einstein equivalence principle. Based on this model, we derive the corresponding phase shifts for atomic clocks and atom interferometers and study their differences. Consequently, we identify a large class of atom-interferometer geometries which measure violations of the universality of the gravitational redshift.

[1] Nat. Commun. **2**, 505 (2011) [2] arXiv:1810.06744 (2018)

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) due to an enactment of the German Bundestag under grant number DLR 50WM1956 (QUANTUS V).

Q 54.11 Thu 16:30 Empore Lichthof

Atomic Raman diffraction from a relativistic perspective — •Butrint Pacolli[1], Alexander Friedrich[1], Enno Giese[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, D-89077 Ulm, Germany

Atom interferometers are not only based on spatial superpositions of different branches that cause interference, but due to their internal structure they also possess an additional degree of freedom. The superposition of internal states has led to the concept of quantum clock interferometry [1] with the measurement of special-relativistic effects [2] and schemes susceptible to the gravitational redshift with transitions during the interferometer sequences [3]. One method to simultaneously manipulate both the external and internal degrees of freedom is Raman diffraction. For a consistent description, and to achieve the needed sensitivity for such measurements, this process has to be treated relativistically. We introduce a relativistic treatment for atomic Raman diffraction based on different masses associated with each internal state and discuss consequences for the diffraction process.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956.

[1] Nat. Commun. **2**, 505 (2011)
[2] Sci. Adv. **5**, eaax8966 (2019)
[3] arXiv 1810.06744, (2018)

Q 54.12 Thu 16:30 Empore Lichthof

Double Raman diffraction for atom optics — •Sven Abend[1], Matthias Gersemann[1], Martina Gebbe[2], Simon Kanthak[3], Christian Schubert[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 Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Atom interferometry based on Raman diffraction is a well-proven tool for precise measurements of gravity, rotation, and fundamental constants. While in free fall, Raman diffraction using a two photon process occurs in a single direction, under vanishing atomic velocity so-called symmetric double diffraction occurs by scattering four photons of a retro-reflected laser beam. We report on a novel realization of a compact and highly integrated laser system based on established telecom fiber technology, electro-optic modulation and frequency doubling for Raman double diffraction of ^{87}Rb atoms. We efficiently drive Raman diffraction with this laser system and perform high contrast atom interferometry using delta-kick collimated condensed atoms generated on an atom chip.

Supported by DLR with funds provided by the BMWi under Grant No. DLR 50WM1552-1557 (QUANTUS-IV-Fallturm) and 50RK1957 (QGYRO), the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL), the CRC 1227 DQmat within projects A05 and B07 and the QUEST-LFS. Funded by the DFG under Germany's Excellence Strategy, EXC-2123-B02.

Q 54.13 Thu 16:30 Empore Lichthof

Compact diode laser system and ground testbed for dual-species atom interferometry with Rb and K on an sounding rocket — •Oliver Anton[1], Victoria Henderson[1], Klaus Döringshoff[1], Julia Pahl[1], Simon Kanthak[1], Benjamin Wiegand[1], Moritz Mihm[3], Ortwin Hellmig[4], André Wenzlawski[3], Patrick Windpassinger[3], Markus Krutzik[1,2], Achim Peters[1,2], and The MAIUS Team[1,2,3,4,5,6] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]Institut für Physik, JGU Mainz — [4]ILP, Universität Hamburg — [5]ZARM, Universität Bremen — [6]IQO, Leibniz Universität Hannover

The MAIUS 2/3 missions will perform dual-species atom interferometry with Bose-Einstein condensates onboard sounding rockets. This suborbital platform enables longer timescales of microgravity than any ground based facility, paving the way towards high-precision tests of Einstein's Equivalence principle. A laser system for such conditions requires special designs for vibrational loads as well as the need for fast autonomous control. This contribution presents the design of our laser system for these missions in detail including key components of the laser system such as micro-integrated diode lasers and Zerodur-based optical benches. Additionally, recent developments of our ground testbed activities in establishing a Rb/K dual-species quantum gas experiment will be described. 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 DLR50WP1432.

Q 54.14 Thu 16:30 Empore Lichthof

Simulations of Integrated Laser-Guided Atom Interferometers — •Matthew Glaysher, Florian Fitzek, Sina Loriani, Ernst Maria Rasel, and Naceur Gaaloul — Leibniz Universität Hannover, Institute of Quantum Optics, Germany

Atom interferometry provides a highly accurate measurement tool, its applications ranging from inertial sensing and navigation to tests of fundamental physics. High precision interferometry is achieved either by Large Momentum Transfer or long interrogation times. Whereas the more common light pulse interferometer schemes can produce the necessary momentum transfer, guided interferometers can achieve long interrogation times. For guided ensembles it is essential to understand the internal interactions, as well as the inherent systematics they cause, to realize a phase-sensitive interferometer. For this purpose we compute the dynamics of Bose-Einstein Condensates (BECs) by numerically solving the Gross-Pitaevskii-Equation. We specifically investigate beam-splitting mechanisms and the phase evolution of BECs in a guided system, realized by dynamically shaped cavity modes or painted potentials.

The presented work is supported by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL)

Q 54.15 Thu 16:30 Empore Lichthof

Universal atom interferometry simulator for precision sensing — •Florian Fitzek[1,2], Jan-Niclas Siemss[1,2], Holger Ahlers[2], Ernst M. Rasel[2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institut für Theoretische Physik, LU Hannover — [2]Institut für Quantenoptik, LU Hannover

Quantum sensors based on light-pulse atom interferometers allow for high-precision measurements of inertial and electromagnetic forces, accurate determination of fundamental constants as the fine structure constant α or to test foundational laws of modern physics as the equivalence principle. The full potential, i.e. sensitivity of these schemes unfolds when large interrogation times or macroscopic arm separation could be implemented. Both directions, however, imply a substantial deviation from an ideal interaction of light with atomic systems. Indeed, real-life complications as finite pulse areas and fidelities, momentum width broadening of the cold clouds, atomic interactions or light fields distortions limit the measurements but more dramatically hinder a reasonable systematics study. This is mainly due to the limited number of analytical cases and to the realistic numerical calculations being intractable.

In this study, we contribute to the precise formulation and simulation of the aforementioned effects by employing a position space solver of the Gross-Pitaevskii equation. We specifically target problems connected to gravity sensing as well as the dephasing in trapped atom interferometers. The work is supported by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 54.16 Thu 16:30 Empore Lichthof

Challenging General Relativity with Matter Wave Interferometry — •Thomas Hensel[1], Christian Schubert[1], Christian Ufrecht[2], Dennis Schlippert[1], Ernst Rasel[1], Enno Giese[2], and Naceur Gaaloul[1] — [1]Institute of Quantum Optics, Leibniz University Hanover, Welfengarten 1, D-30167 Hanover — [2]Institut für Quantenphysik (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm

Two decades ago the first data for a free-fall comparison of a quantum object and a macroscopic object has been taken, paving the way towards tests of the Universality of Free Fall in the quantum realm. Yet it was debated, whether this constitutes an atom interferometric redhsift test.

We conduct a study of tests of the Einstein Equivalence Principle with Matter Wave Interferometry with a focus on the Universality of the Gravitational Redshift and investigate experimental implementations in the VLBAI facility in Hannover. An analysis of the systematic errors lets us conclude that tests of the Universality of the Gravitational Redshift utilizing atom interferometers are in principle possible.

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Q 54.17 Thu 16:30 Empore Lichthof

Path-dependent wave-packet propagation for atom interferometry — •Amelie Mayländer[1], Alexander Friedrich[1], Enno Giese[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, Albert-Einstein-Allee 11, D-89069, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, D-89077 Ulm, Germany

Light-pulse atom interferometers have become an instrument for high-precision measurements of accelerations and rotations by determining the phase difference between two branches of the interferometer. Efficient calculation schemes are required to predict and investigate experimental results.

In our contribution we focus on the influence of time- and space-dependent potentials on atom interferometers. We present a numerical method based on comoving frames along each branch to efficiently calculate the impact of an arbitrary potential on the propagation of atomic wave packets in an atom interferometer.

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Q 54.18 Thu 16:30 Empore Lichthof

Efficient modeling and numerics for matter-wave beamsplitters in 3D — •Samuel Böhringer[1], Alexander Friedrich[1], Enno Giese[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, Albert-Einstein-Allee 11, D-89069, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, D-89077 Ulm, Germany

Light-pulse atom interferometers have evolved into capable sensors for inertial and electromagnetic forces and are now routinely used to test the foundations of physics. Most matter-wave interferometers use Raman or Bragg diffraction in combination with large-momentum-transfer techniques for for atomic diffraction. Typically, beamsplitters have multiple sources of imperfection such as mirror vibrations, polarization imperfections or general imperfections in their optical beams. In order to analyze and quantify the consequences in detail, full 3d models of these processes are necessary. However, due to the interplay of multiple effects the analytic treatment becomes cumbersome. In order to gain a deeper understanding of these effects a numerical treatment is necessary and needs to be efficient. In our contribution we discuss the modeling of Raman diffraction with physical beam shapes and other imperfections of the lasers involved.

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Q 54.19 Thu 16:30 Empore Lichthof

Non-perturbative treatment of quasi-Bragg diffraction phases for atom interferometry — •Jan-Niclas Siemss[1,2], Florian Fitzek[2], Sven Abend[2], Ernst M. Rasel[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

Bragg diffraction is a cornerstone of light-pulse atom interferometry. High-fidelity Bragg pulses for atomic sources with a finite velocity distribution typically operate in the quasi-Bragg regime. While enabling an efficient population transfer, the diffraction phase and its dependence on the pulse parameters are currently not well characterized despite playing a key role in the systematics of the interferometer.

In our work, we formulate Bragg diffraction in terms of scattering theory. We provide an intuitive understanding of the Bragg condition and derive a unitary scattering matrix in case of adiabatic driving with Gaussian pulses. We find, that perturbations of the adiabatic solution are well described by Landau-Zener physics. Furthermore, we include the effects of linear Doppler shifts applicable to narrow atomic velocity distributions on the scale of the photon recoil of the optical lattice.

As an illustration, with our comprehensive microscopic model we study diffraction phase shift fluctuations caused by laser intensity noise affecting the sensitivity of a Mach-Zehnder atom interferometer.

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Q 54.20 Thu 16:30 Empore Lichthof

Detecting gravitational waves with atom interferometers — •Christian Schubert, Dennis Schlippert, Sven Abend, Sina Loriani, Naceur Gaaloul, Wolfgang Ertmer, and Ernst M. Rasel — Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover

The combination of two atom interferometers enables geometries sensitive to the strain induced by a gravitational wave. This contribution will introduce the operation principle of atom interferometers for gravitational wave detection and highlight the key parameters which can e.g. be adjusted to close the gap between the laser interferometers Virgo, aLIGO, and LISA. Addressing this scenario, the contribution will discuss advantages and disadvantages of specific interferometer schemes, experimental demonstration activities, and put these into perspective for the proposed European infrastructure ELGAR.

The authors acknowledge support by the CRC 1227 DQ-mat (B07), the DLR with funds provided by the BMWi due to an enactment of the German Bundestag under Grant No. 50WM1952, 50RK1957, the DFG under Germany's Excellence Strategy - EXC-2123-B2, and “Niedersächsisches Vorab" through the “Quantum- and Nano- Metrology (QUANOMET)" initiative (project QT3).

Q 54.21 Thu 16:30 Empore Lichthof

Towards light induced dipole-dipole interaction — •Marion Mallweger[1], Mira Maiwöger[1], Filippo Borselli[1], Tiantian Zhang[1], Jörg Schmiedmayer[1], Matthias Sonnleitner[2], and Philipp Haslinger[1] — [1]Atominstitut TU Vienna, Vienna, Austria — [2]Universät Innsbruck, Innsbruck, Austria

Atom interferometers have proven to be an ideal platform for measuring extremely small forces. However, their high sensitivity to potential energy changes can also be used to measure interactions between atoms. A particular case of these are light-induced dipole-dipole interactions, which are predicted to even be caused by incoherent, off-resonant light fields. We will present our preliminary findings and discuss, in an intuitive way, the geometry of our interferometer design.

Q 54.22 Thu 16:30 Empore Lichthof

Space-borne quantum test of the weak equivalence principle at the 10^{-17} level — •Sina Loriani, Sven Abend, Dennis Schlippert, Christian Schubert, Ernst Maria Rasel, and Naceur Gaaloul — Institut für Quantenoptik and Centre for Quantum Engineering and Space-Time Research (QUEST), Leibniz Universität Hannover, Welfengarten 1, D- 30167 Hannover, Germany

Matter wave interferometry provides a unique access to the interface of quantum theory and gravity and is well suited for probing various aspects of general relativity, ranging from its postulates as the equivalence principle to its implications such as gravitational waves. In this contribution, we present a dedicated satellite mission for testing the universality of free fall to 10^{-17} as proposed for the ESA Voyage 2050 initiative. The theoretical advances and technological maturity that would allow reaching this performance will be highlighted.

We acknowledge financial support from DFG through CRC 1227 (DQ-mat), project B07, CRC 1128 geo-Q, EXC-2123 Quantum Frontiers, the German Space Agency (DLR) with funds provided by the BMWi due to an enactment of the German Bundestag under grant nos. 50WM1641, 50WM1556, 50WM1956, and 50WM0837, as well as by ”Niedersächsisches Vorab” through the QUANOMET initiative (QT3) and through ”Förderung von Wissenschaft und Technik in Forschung und Lehre” for the initial funding of research in the new DLR-SI Institute. D.S. acknowledges funding by the Federal Ministry of Education and Research through the funding program Photonics Research Germany under contract number 13N14875.

Q 54.23 Thu 16:30 Empore Lichthof

Setup for a transportable quantum gravimeter — •Jannik Wesche[1], Nina Heine[1], Jonas Matthias[1], Maral Sahelgozin[1], Waldemar Herr[1], Sven Abend[1], Jürgen Müller[2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Erdmessung, Leibniz Universität Hannover

The transportable quantum gravimeter QG-1 strives for unprecedented accuracy opening up new geodetic applications, for example in hydrology. This poster will give an overview of the transportable QG-1 setup utilising matter-wave interferometry with Bose-Einstein condensates (BECs) of ^{87}Rb atoms. The BEC is created at the top of a dropping tube using atom chip technology. The atoms, acting as test masses for the measurement, are released into free fall under precise control of their external and internal degrees of freedom. To manipulate and interrogate the atoms a fibre-based miniaturised laser system is used. Together with the control electronics, it is integrated into a temperature stabilised rack. The presented compact design and the mobile rack integration grant QG-1 the possibility to measure local gravity at sites of interest for geodesy and geoscience.

We acknowledge financial support from "Niedersächsisches Vorab" through "Förderung von Wissenschaft und Technik in Forschung und Lehre" for the initial funding of research in the new DLR-SI Institute and by the Deutsche Forschungsgemeinschaft (DFG) in the project A01 of the SFB 1128 geo-Q and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 54.24 Thu 16:30 Empore Lichthof

Characterisation of adhesive integration technologies for miniaturized optical setups in UHV — •Anne Stiekel[1,2], Marc Christ[1,2], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [2]Institut für Physik, Humboldt-Universität zu Berlin

Quantum technologies based on cold atoms allow for applications (e.g. timekeeping, sensing and communications) in the field and on space-based platforms. To access non-laboratory platforms, miniaturization of these systems into compact, rugged devices is an essential requirement. Besides physics package and electronics, this also includes miniaturization of the optical distribution and beam manipulation systems, ideally to be used in the UHV environment. Hence the used materials, components and integration technologies have to meet challenging demands regarding thermal and mechanical durability, as well as ultra-low outgassing.

To qualify the UHV-compatibility, an versatile system is being set up for residual gas analysis and measurement of total gas rates down to $5 \cdot 10^{-10}$ mbar l s^{-1}. This poster gives an overview of the UHV-system architecture, first results from its commissioning and our qualification test on optical components and integration technologies.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1648, 50WM1949 and 50RK1978.

Q 54.25 Thu 16:30 Empore Lichthof

Entwicklung und Charakterisierung eines hochpräzisen Werkzeugs zur Laserstrahlausrichtung — •Kim Niewerth, Lea Bischof, Stefan Ast, Max Rohr, Daniel Penkert, Katharina-Sophie Isleif, Oliver Gerberding, Karsten Danzmann und Gerhard Heinzel — Albert-Einstein-Institut, Hannover, Deutschland

In Forschungsmissionen wie LISA oder Grace Follow-on werden präzise und hochauflösende Messmethoden zur Vermessung von Gravitationswellen sowie des Erdschwerefelds genutzt. Dabei ermöglichen optische Systeme in Form von monolithischen Interferometern die Messung von Verschiebungen mit Pikometer- und Nanometerauflösung. Das Albert-Einstein-Institut in Hannover verwendet in seinen Reinraumanlagen hochpräzise Werkzeuge für den Bau von Prototypen der Flughardware. Im Bauprozess werden diese Werkzeuge benötigt, um die hohen technischen Anforderungen von Pikometerstabilität zu erfüllen. Eines dieser Hilfsmittel ist eine kalibrierte Quadrantenphotodiode (cQP), an der zurzeit gearbeitet wird. Diese soll es ermöglichen, den Verlauf von Laserstrahlen zu bestimmen. Bei diesem Verfahren ist die aktive Fläche einer Photodiode in vier Quadranten unterteilt. Durch den Ausgleich der Leistungen in den vier einzelnen Quadranten kann die Position des Strahls auf der Photodiode zentriert werden. Mithilfe einer Koordinatenmessmaschine wird durch einen komplexen Kalibrierungsprozess die Position des Strahls ermittelt. Um die Vorteile des cQP zu nutzen, wird ein Hexapod verwendet, der die Positionierung und Manipulierung im um-Bereich ermöglicht.

Q 54.26 Thu 16:30 Empore Lichthof

Simulation of femtosecond pulse in a Kerr-lens mode-locked Ti:sapphire laser — •Nomin-Erdene Erdenebat, Khosochir Tsogvoo, Munkhbaatar Purevdorj, Baatarchuluun Tsermaa, and Davaasambuu Jav — Laser Research Center, National University of Mongolia, Mongolia

The Kerr-lens mode-locking (KLM) is known as a suitable method for generation of femtosecond pulses and mode-locked Ti:sapphire laser is now widely used sources of stable, energetic femtosecond pulses. We will present the simulation of KLM in Ti:sapphire laser cavities with a folded-cavity four-mirror by applying the ABCD ray-tracing technique for a Gaussian beam. Simulations will be performed for an asymmetric resonator design. Based on the numerical analysis, we will find the optimum design parameters (slit position, gain cavity spacing, gain medium position) for KLM. This work has been done with financial support of the Mongolian Foundation for Science and Technology.

Q 54.27 Thu 16:30 Empore Lichthof

Experimental Realisation of PT-Symmetric Flat Bands — •Tobias Biesenthal, Mark Kremer, Matthias Heinrich, and Alexander Szameit — Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany

Shaping the flow of light remains one of the core objectives in optics, and is inextricably linked to the concept of flat dispersion bands. At the same time, parity-time symmetric photonics provides new insights into the interplay of the real- and imaginary parts of complex potentials. We experimentally demonstrate that flat bands and compact localized states can be established at exceptional points of PT-symmetric lattices. Hence, even in scenarios aiming to arrest the propagation and diffractive broadening of optical signals, losses are not necessarily detrimental, and can serve as key ingredient in achieving photonic flat band responses in non-Hermitian environments.

Q 54.28 Thu 16:30 Empore Lichthof

Theoretical description of the plasmon-exciton coupling in organic-metallic hybrid systems — •Fabian G. Dröge[1,2], Alexander Schubert[1,2], and Stefanie Gräfe[1,2] — [1]Institut für Physikalische Chemie, Helmholtzweg 4, 07743 Jena, Germany — [2]Abbe Center of Photonics, Albert-Einstein-Str. 6, 07745 Jena, Germany

Nanoplasmonics is a new field of research emerging on the interface of atomic, molecular, and solid-state physics as well as (nano-)chemistry. Here, the interaction between metallic nanoparticles, electromagnetic fields, and an adjacent molecular system are described and evaluated.

We focus on the development of a self-consistent theoretical treatment of coupled metallic-organic hybrid materials from an electromagnetic, quantum chemical & dynamical perspective for an in-depth understanding of the dynamics of the combined hybrid system.

In this contribution we present the first results of our simulation of a coupled excitonic-plasmonic hybrid model system. Upon interaction with a time-dependent laser field, the inorganic metal model gives rise to a localised surface plasmon while a Frenkel exciton is formed on the organic molecular aggregate. The coherent temporal evolution of the coupled system is then simulated by numerically solving the time-dependent Schrödinger equation. Possible approaches towards the implementation will be discussed and the underlying approximations critically evaluated.

Q 54.29 Thu 16:30 Empore Lichthof

Simulations of Dipole Emitters Coupled to Inverted Cone Nanopillar Diamond Structures — •Cem Güney Torun[1] and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

Single, optically active quantum systems, such as single photon sources and quantum memories are building blocks for quantum technologies. In order to achieve sensitive quantum sensors, or quantum communication devices with high communication rates, we require efficient optical coupling to such quantum systems. In this work, we focus on a device that is simple in design and easy to produce but still enables photon extraction efficiencies as high as in more complex designs. In particular, we optimize numerically coupling efficiencies of a dipole emitter inside an inverted diamond nanocone to a single mode optical fibre. From our simulations we determine dipole to fibre mode coupling efficiencies of up to 86% extracted from overlap integrals between far-field intensity distribution and Gaussian fibre mode.

Q 54.30 Thu 16:30 Empore Lichthof

Integration of organic macromolecular compounds with nanophotonic waveguides — Alexander Eich[1], •Christian A. Strassert[2], and Carsten Schuck[1] — [1]Institute of physics, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]2 Institute of inorganic and analytic chemistry, University of Münster, Corrensstr. 28, 48149 Münster, Germany

The integration of quantum emitters with nano-photonic circuits enables quantum optic experiments on monolithic silicon chips. However, controlling the positioning of single nano-scale emitters or arrays of single emitters relative to nanophotonic structures is a major challenge for realizing integrated quantum light sources supplying photonic integrated circuits with single-photons.

In our work, we employ Silicon(IV) Phthalocyanine (SiPc) molecules as nano-emitters, which show distinguished photostability [1]. We embed SiPc molecules into a PMMA host matrix, which allows for thin-film application on top of prefabricated tantalum pentoxide (Ta2O5) waveguides. Lithographic patterning of the PMMA-thin film then achieves the desired overlay accuracy with respect to the nanophotonic devices. Here we report on the excitation of the molecules and collection of their fluorescent light through nano-photonic waveguides, thus paving the way for integrated quantum photonic experiments.

[1] A. J. Pearson et al., Journal of Materials Chemistry C 5.48, doi: 10.1039/c7tc03946h (2017)

Q 54.31 Thu 16:30 Empore Lichthof

Design of a cryogenic Low Noise Amplifier — •Roland Jaha[1,2,3], Manuel Delgado-Restituto[4,5], Jorge Fernández-Berni[4,5], Ricardo Carmona Galán[4,5], Matthias Häussler[1,2,3], Martin A. Wolff[1,2,3], and Carsten Schuck[1,2,3] — [1]Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]SoN - Center for Soft Nanoscience, Busso-Peus-Str. 10, 48149 Münster, Germany — [4]University of Seville, C/S. Fernando 4, 41004 Seville, Spain — [5]Instituto de Microelectrónica IMSE-CNM, Cl Américo Vespucio 28, 41092 Seville, Spain

Microwave low noise amplifiers (LNAs) are essential signal processing components of a very large number of scientific systems that are naturally concerned with low temperature environments. However, state-of-the-art LNAs are typically operated at room temperature and suffer from high noise temperatures in the radio frequency (RF) range. Here we show how significantly reduced noise temperatures below 15 K can be achieved with cryogenic LNAs. We exploit the high carrier mobility and low loss of silicon-germanium heterojunction bipolar transistors at cryogenic temperatures and optimize amplifier designs for RF signals originating from superconducting nanowire single photon detectors. We achieve LNA designs providing >4 GHz bandwidth signal amplification with up to 45 dB gain, dissipating only 5 mW of power. Our results will allow for significantly enhanced small-signal processing at cryogenic temperatures with minimal impact on the thermal budget.

Q 54.32 Thu 16:30 Empore Lichthof

Self-focusing of Bose-Einstein condensates — •Patrick Boegel[1], Matthias Meister[1], Jan-Niclas Siemss[2], Naceur Gaaloul[2], Maxim A. Efremov[3], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Ulm, Germany — [2]Institut für Quantenoptik, Leibniz University Hannover, Hannover, Germany — [3]Institut für Quantentechnologien, Deutsches Zentrum

für Luft- und Raumfahrt (DLR), Ulm, Germany

The standard way to control the position and the strength of maximal focusing of a matter-wave is to use a lens which imprints a position-dependent phase on the initial wave. However, quantum mechanics allows focusing even without a lens [1,2], based on diffractive focusing, where the initial wave function is a real-valued one with a non-Gaussian shape. Hence, the problem of optimal focusing translates into finding an appropriate initial wave function [3]. We explore the phenomenon of diffractive focusing of an atomic Bose-Einstein condensate (BEC) in the regime, where the resonant atom-atom interaction plays a key role, and describe this effect in phase space within the Wigner function approach.

This project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under the grant numbers 50WP1705 and 50WM1862.

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[2] Weisman D. et al. Phys. Rev. Lett. 118, 154301 (2017)
[3] Vogel, K. et al., Chem. Phys. 375, 133-143 (2010)

Q 54.33 Thu 16:30 Empore Lichthof

Anomalous Floquet topological phases in periodically-driven hexagonal lattices — •Karen Wintersperger[1,2], Christoph Braun[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstraße 4, 80799 München — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Ultracold atoms in periodically-driven optical lattices can be used to simulate systems with nontrivial topological properties. Due to the periodic driving, energy conservation is relaxed which makes it possible to realize systems with properties that go beyond those of conventional static systems. For instance, chiral edge modes can exist even if the bulk is topologically trivial [1].

We study such anomalous Floquet phases experimentally using a BEC of K39 in an optical honeycomb lattice with periodically modulated tunnel couplings. By monitoring the closing and reopening of energy gaps in the band structure we are able to track the transitions between different Floquet phases. Moreover, we probe the topological porperties of the bulk by measuring the Hall deflection induced by local changes in the Berry curvature. Combining these measurements enables us to extract the topological invariants of the bulk bands and the energy gaps, which are both required to accurately classify the topological phases of Floquet systems [2, 3].

[1] T. Kitagawa et al., Phys. Rev. B 82, 235114 (2010) [2] M. Rudner et al., PRX 3, 031005 (2013) [3] N. Ünal et al., PRL 122, 253601 (2019)

Q 54.34 Thu 16:30 Empore Lichthof

Ground state and dynamics of shell-shaped BEC mixtures — •Alexander Wolf[1], Matthias Meister[1], Maxim A. Efremov[2], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt (DLR), D-89077 Ulm, Germany

Recently, there has been great interest in the properties of hollow Bose-Einstein condensates (BECs), which are generated nowadays with radio-frequency (rf) dressing [1]. As an alternative method, we propose to realize hollow BECs by utilizing a dual-species mixture. A proper choice of the parameters allows us to create a ground state where one species is in the center and generates a repulsive effective potential for the second species, giving rise to a shell-shaped BEC [2]. In order to obtain the main properties of this setup, in particular the width of the outer shell, we employ the Gross-Pitaevskii equation within the Thomas-Fermi approximation. Moreover, we investigate the spectrum of collective excitations with an emphasis on the transition from a filled to a hollow geometry. In the latter case, a new inner boundary appears, leading to a change of the collective mode spectrum.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WP1705.

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[2] Riboli, F., et al., Phys. Rev. A 65, 063614 (2002)

Q 54.35 Thu 16:30 Empore Lichthof

Stabilization of a dark soliton by localised dissipation — •Alexandre Gil Moreno[1], Christian Baals[1,2], Jens Benary[1], Marvin Röhrle[1], Jian Jiang[1], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Germany

We numerically study the stability of a dark soliton in a 3D system using the Gross-Pitaevskii equation with an imaginary potential. Our starting point is the ground state of a Bose-Einstein condensate in an elongated harmonic trap with a dark soliton. This initial state decays due to the sneaking instability, which means that the dark soliton eventually turns into a vortex ring. By applying local losses (i.e. a local imaginary potential) at the centre, we observe a slow down of the decay with increasing imaginary potential. Above a critical dissipation strength, the soliton becomes stabilised (within our computational time).

Q 54.36 Thu 16:30 Empore Lichthof

High fidelity two-qubit quantum gate with neutral atoms — •Hui Sun[1,2], Bing Yang[1,2], Han-yi Wang[1,2], Zhen-sheng Yuan[1,2], and Jian-wei Hui[1,2] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

Cold neutral atoms hold great promise for constructing a quantum device that outperform the classical computer. However, the imperfections of gate operations hinder the implementation of fault-tolerant quantum computing, which requires the operation error to be lower than the threshold 10^{-2}. Here, we report on a high-fidelity two-qubit gate entangling 1250 pairs of neutral atoms in parallel with a operation error of $7(1) \times 10^{-3}$. By improving the precision of controlling the lattice potential, the gate operation driven by the second-order superexchange interaction achieve the same energy scale as the on-site interaction of the Hubbard model. The coherence time is prolonged and the decoherence of entanglement in optical lattice is mainly governed by the intrinsic light scattering. We calibrate the gate fidelity to be 99.3(1)% by measuring spin correlations of the quantum state after multiple gates performed on the atom pairs. Our experiment represents a benchmark towards fault-tolerant quantum computing with neutral atoms.

Q 54.37 Thu 16:30 Empore Lichthof

Phasonic Spectroscopy of a Quantum Gas in a Quasicrystalline Lattice — Shankari V. Rajagopal[1], Toshihiko Shimasaki[1], Peter Dotti[1], •Mantas Raciunas[2], Ruwan Senaratne[1], Egidijus Anisimovas[2], André Eckardt[3], and David M. Weld[1] — [1]Department of Physics, University of California, Santa Barbara, California 93106, USA — [2]Institute of Theoretical Physics and Astronomy, Vilnius University, Sauletekio 3, LT-10257 Vilnius, Lithuania — [3]Max-Planck-Institut fur Physik komplexer Systeme, Nothnitzer Str. 38, 01187 Dresden, Germany

Phasonic degrees of freedom are unique to quasiperiodic structures, and play a central role in poorly-understood properties of quasicrystals from excitation spectra to wavefunction statistics to electronic transport. However, phasons are challenging to access dynamically in the solid state due to their complex long-range character and the effects of disorder and strain. We report phasonic spectroscopy of a quantum gas in a one-dimensional quasicrystalline optical lattice. We observe that strong phasonic driving produces a nonperturbative high-harmonic plateau strikingly different from the effects of standard dipolar driving. Tuning the potential from crystalline to quasicrystalline, we identify spectroscopic signatures of quasiperiodicity and interactions and map the emergence of a multifractal energy spectrum, opening a path to direct imaging of the Hofstadter butterfly.

Q 54.38 Thu 16:30 Empore Lichthof

Dirty Fermions — •André Becker and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We consider fermionic atoms in a harmonic trapping potential and analyze the impact of a frozen random environment in the BCS regime. To this end we investigate the effect of either laser speckles or impurity disorder upon the Cooper pairing of fermions without population imbalance. In close analogy to the corresponding case study [1] in the BEC regime, we treat disorder perturbatively as well as nonperturbatively, and focus, in particular, upon the question how the Thomas-Fermi radii of the cloud depend on the disorder strength. Finally, we discuss our findings in view of Anderson's theorem which states that superconductivity is robust with respect to non-magnetic disorder in the host material [2].

[1] B. Nagler, M. Radonjic, S. Barbosa, J. Koch, A. Pelster, and A. Widera, arXiv:1911.02626
[2] P.W. Anderson, J. Phys. Chem. Solids. **11**, 26 (1959)

Q 54.39 Thu 16:30 Empore Lichthof

Towards a Lithium Quantum Gas Microscope for Tailored Few-Body Systems — •Mathis Fischer, Andreas Kerkmann, Michael Hagemann, Justus Brüggenjürgen, Tobias Petersen, Klaus Sengstock, and Christof Weitenberg — Institute for Laser Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We are setting up a new quantum gas microscope for the preparation and detection of degenerate samples of ^{6}Li/^{7}Li atoms to study strong correlations in small quantum systems.

Our setup features a compact 2D-/3D-MOT loading scheme, subsequently followed by a lambda-enhanced gray molasses. This allows for an all optical cooling approach of our atomic samples to degeneracy in a crossed optical dipole trap. Since we avoid an additional atom transport, this setup supports short cycle times.

We report on the realization of a molecular BEC of fermionic ^{6}Li atoms in the focal plane of a high-resolution imaging setup by using a well-controlled intensity ramp for the evaporation that circumvents thermal effects in acousto-optical modulators. In addition, we will present the loading of the BEC into a 2D triangular lattice and a 1D accordion lattice.

In the future, we will look at few-body systems in specifically tailored optical potentials to study new regimes, e.g., ionization dynamics in artificial atoms or fractional Quantum Hall physics in rotating microtraps. In this poster, we provide information about the details of the design, the current status of the experiment and our future plans.

Q 54.40 Thu 16:30 Empore Lichthof

Topological effects in Floquet-engineered ultracold matter — Luca Asteria[1], •Henrik Zahn[1], Marcel Kosch[1], Bojan Hansen[1], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut für Laserphysik, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg, Hamburg, Germany

Ultracold atoms in optical lattices constitute a versatile platform to study the fascinating phenomena of gauge fields and topological matter. Periodic driving can induce effective Floquet Hamiltonians with non-trivial Chern number and thus paradigmatic models, such as the Haldane model on the honeycomb lattice, can be directly engineered. Here we present our recent experiments, in which we realized new approaches for measuring the Chern number in this system and map out the Haldane phase diagram. This includes quantized circular dichroism as a dissipative analog of the quantized Hall conductance as well as time-resolved Bloch-state tomography allowing for the observation of a dynamical linking number. These experiments define an excellent starting point for the exploration of interacting topological phases with ultracold atoms.

Q 54.41 Thu 16:30 Empore Lichthof

Floquet-phases in Optical Kagome Lattices — •Marcel Kosch[1], Luca Asteria[1], Henrik Zahn[1], Bojan Hansen[1], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut für Laserphysik, Universität Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg, Germany

The Kagome lattice is a hexagonal lattice with a three-atomic basis and has received considerable interest due to its flat band, which should give rise to spin liquid phases. While naturally the uppermost of the three bands is flat, this structure can be inverted by applying Floquet shaking.

Already at smaller shaking amplitudes, a circular shaking induces topological bands analogous to the Haldane model in the driven honeycomb lattice, however, with a more favorable flatness ratio between the band width and band gap. It is therefore a promising starting point for the study of interacting topological phases.

In this poster, we present a numerical study of the topological phase diagram of the driven optical Kagome lattice. We also recall how it can be realized as a hexagonal superlattice from two commensurate wavelengths and describe how it will be realized in our setup of ultracold fermionic and bosonic quantum gases.

Q 54.42 Thu 16:30 Empore Lichthof

Manipulating the complex-valued temporal shape of a photon — •Stefan Langenfeld, Olivier Morin, Matthias Körber, Philip Thomas, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Single photons are the most used carrier to transfer qubits over a quantum network. Over the last decades many platforms were developed in order to absorb and emit single photons. To stay in the quantum regime, the success of these operations relies on the perfect control of all degrees of freedom of the electromagnetic field. The temporal mode function is explicitly challenging to handle experimentally. Most platforms do not offer large and accurate flexibility on this particular degree of freedom making the connection of multiple devices difficult. Here, we investigate thoroughly the possibilities offered by a cavity quantum electrodynamics (QED) system, namely a single ^{87}Rb atom in a high finesse cavity. Starting from previous theoretical works [1,2], we developed a comprehensive and exhaustive model of our system [3]. Thanks to this, we experimentally demonstrate a very high control of the temporal mode of a single photon in amplitude and phase. This opens up various possibilities as for instance modifying the temporal shape by 3 orders of magnitude in bandwidth. It also shows that our platform can be compatible with many others and can even be used as a photon shape converter.

[1] A. Gorshkov *et al.*, Phys. Rev. A **76**, 033804 (2007).
[2] L. Giannelli *et al.*, New J. Phys. **20**, 105009 (2018).
[3] O. Morin *et al.*, Phys. Rev. Lett. **123**, 133602 (2019).

Q 54.43 Thu 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 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., ArXiv 1909.00859 (2019)

Q 54.44 Thu 16:30 Empore Lichthof

Generation of non-classical light states with an optical cavity — •Lukas Hartung[1], Severin Daiss[1], Bastian Hacker[1,2], Stephan Welte[1], Stephan Ritter[1,3], Lin Li[1,4], Emanuele Distante[1], and Gerhard Rempe[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Present address: Max-Planck-Institut für die Physik des Lichts, Staudtstr. 2, 91058 Erlangen — [3]Present address: TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Gräfelfing, Germany — [4]Present address: School of Physics, Huazhong University of Science and Technology, Wuhan, China

Engineering quantum states of light is a long standing goal in quantum optics which finds significant applications in quantum communication and quantum information technologies. On this poster, we demonstrate the production of different non-classical light states. Our protocol is based on the interaction of an impinging laser pulse with a single atom trapped in a high-finesse optical resonator. As a result of this interaction, the light pulse gets entangled with the internal state of the atom. A suitable subsequent measurement on the atomic state can be used to engineer different output light states. This allows us to produce single photons out of coherent input light with arbitrary temporal mode profiles [1] as well as to generate optical cat states [2].

[1] Daiss, Welte, Hacker, Li and Rempe, Phys. Rev. Lett. 122, 133603 (2019)
[2] Hacker, Welte, Daiss, Shaukat, Ritter, Li and Rempe, Nat. Photon.

13, 110 (2019)

Q 54.45 Thu 16:30 Empore Lichthof

Satellite- vs Ground-based quantum networks and the role of quantum repeaters — •Carlo Liorni, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität, Düsseldorf, Germany

Entanglement distribution over global distances (thousands of km) is a very daunting task. The exponential losses experienced during the propagation of light in optical fibres limit the achievable distances to ~ 200 km in practice. A possible solution consists in the use of quantum repeaters, based on entanglement swapping or quantum error correction. Satellite-based optical links can be very advantageous in this case, as the losses scale only quadratically with the distance, when atmospheric effects are small. In this work, we analyse a scheme that combines these two ingredients, ground-based quantum repeaters and satellite-based links in the downlink configuration, in order to achieve long distance entanglement distribution. The performance of this repeater chain is assessed in terms of the secret key rate achievable by the BB-84 cryptographic protocol, that depends on both the entanglement distribution rate and the quality of the final shared state. The comparison with the fibre-based implementation shows that the satellite-mediated scheme performs better in almost every situation. Finally, we propose an augmented scheme that takes advantage of orbiting quantum repeater stations in order to achieve higher key rates, reliability and flexibility. The integration between satellite-based links and ground repeater networks can be envisaged to represent the backbone of the future Quantum Internet.

Q 54.46 Thu 16:30 Empore Lichthof

Single trapped atoms coupled to crossed fiber cavities — •Pau Farrera[1,2], Dominik Niemietz[1], Manuel Brekenfeld[1], Gianvito Chiarella[1], Joseph Dale Christesen[1,3], and Gerhard Rempe[1] — [1]Max Planck Institute of Quantum Optics, 85748 Garching, Germany — [2]ICFO-The Institute of Photonic Sciences, Barcelona, Spain — [3]NIST, Boulder, Colorado 80305, USA

Recent experimental advancement in the field of optical cavity QED comprises two directions of development: a further reduction of the mode volumes of the resonators, as with 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 [2,3]. We have set up a new experiment that combines these two experimental advancements in a single platform with single neutral atoms trapped at the center of two crossed FFPCs. This novel setup provides new challenges and capabilities, such as the fabrication and assembling of high-finesse fiber cavities, the strong coupling of single atoms to both cavity modes for long trapping times, the atom imaging system, or the microwave manipulation of the atomic states. Some of the mentioned capabilities were recently used to implement a passive, heralded and high fidelity optical quantum memory. In the future, they will enable the development of other novel quantum information processing schemes based on two-mode cavity QED.

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[2] Leonard et al.,Nature 543, 87 (2017)
[3] Hamsen et al., Nat. Phys. 14, 885 (2018)

Q 54.47 Thu 16:30 Empore Lichthof

Wavelength Conversion of Single Photons between the UV and Near-Infrared — •Marcel Hohn and Simon Stellmer — Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn

The Cluster of Excellence ML4Q (Matter and Light for Quantum Computing), a cooperation between the universities of Cologne, Aachen, Bonn, as well as the Research Center Jülich, aims to develop new computing and networking architectures. Several hardware platforms for quantum computing, such as spin qubits and trapped ions, are investigated in the course of the collaboration. The coupling of these systems via single photons for long-distance quantum information transport allows for the development of a heterogeneous network. The interconnection of distinct platforms additionally requires the conversion of the single photons between the respective wavelengths of the systems while preserving quantum correlations. Here we report on the development of a quantum frequency conversion (QFC) setup between the Yb^+ dipole transition at 369.5 nm and InGaAs quantum dots at around 850 nm using sum- and difference frequency generation (SFG/DFG) in a periodically poled potassium titanyl phosphate (PPKTP) waveguide structure.

Q 54.48 Thu 16:30 Empore Lichthof

Towards a coherent spin photon interface for quantum repeaters using color centers in diamond — •Maximilian Pallmann[1], Jonathan Körber[1], Rainer Stöhr[2], Evgenij Vasilenko[1], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Stuttgart

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 is an efficient, coherent spin-photon interface, and coupling single color centers in diamond to a microcavity is a promising approach therefor. In our experiment, we integrate a diamond membrane to an open access fiber-based Fabry-Perot microcavity to attain emission enhancement of color centers into a single well-collectable mode as well as spectral filtering. Simulations predict the feasibility of a strong enhancement of the ZPL emission efficiency, reaching values of up to 80% for NV centers. We present a spatially resolved characterization of a coupled cavity-membrane device and report on the current status of the experiment.

Q 54.49 Thu 16:30 Empore Lichthof

Tight bound on the eavesdropper's information in a multipartite device-independent scenario — •Federico Grasselli, Glaucia Murta, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, Düsseldorf, Germany

The security of device-independent (DI) quantum key distribution (QKD) holds independently of the actual functioning of the quantum devices and is based on the observation of a Bell inequality violation. In the seminal work by Pironio et al. [New J. Phys. 11, 045021 (2009)], the authors derive a tight bound on the eavesdropper's information which only depends on the violation of the Clauser-Horne-Shimony-Holt (CHSH) inequality observed by two parties. In a DI conference key agreement (CKA), the goal is to establish a conference key among several users by relying on a multipartite Bell inequality violation. So far, the security of such protocols either adapts the result of Pironio et al. (tightness not being guaranteed) or relies on loose numerical procedures (Navasqués-Pironio-Acin hierarchy). In this work, we obtain a tight bound on the eavesdropper's information when three parties observe a violation of the Mermin-Ardehali-Belinskii-Klyshko (MABK) inequality. The bound and its derivation can find applications in DICKA protocols. In order to obtain it, we also derive an analytical bound on the maximal violation of the MABK inequality achieved by an arbitrary three-qubit state.

Q 54.50 Thu 16:30 Empore Lichthof

Towards long coherence times for a single atom in a standing-wave dipole trap — •Derya Taray[1], Tim van Leent[1], Robert Garthoff[1], Kai Redeker[1], Matthias Seubert[1], Wei Zhang[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany

Long-distance entanglement distribution is the key ingredient in future quantum networks, which will enable distributed quantum computing and quantum communication. To reach long distances, quantum memories with prolonged coherence times are required. Currently we entangle two Rubidium 87 atoms separated by 400 meters via the entanglement swapping protocol [1,2]. Yet, for increasing the separation by at least one order of magnitude the atomic state coherence is the limiting factor, mainly due to position-dependent dephasing in the strongly focused dipole trap.

In this work, we present results towards the implementation of a standing-wave dipole trap, in which the longitudinal field components, causing the dephasing cancel. Two counter-propagating dipole trap beams are focused to 2 micrometer by high-NA objectives, with active phase and directional stabilization of one beam. This should increase the coherence time to several ms, enabling distribution of atom-photon entanglement with a fidelity of 90% over a distance of 100 km.

[1] W. Rosenfeld et al., Phys. Rev. Lett. 119, 010402 (2017)
[2] T. van Leent et al., arXiv: 1909.01006 (2019)

Q 54.51 Thu 16:30 Empore Lichthof

Quantum Key Distribution with Small Satellites — •Peter Freiwang[3], Lukas Knips[3,5], Leonhard Mayr[3], Wenjamin Rosenfeld[3], QUBE consortium[1,2,3,4,6], and Harald Weinfurter[3,5] — [1]Center for Telematics (ZfT), Würzburg — [2]German Aerospace Center (DLR) IKN, Oberpfaffenhofen —

[3]Ludwig-Maximilian-University (LMU), Munich — [4]Max Planck Institute for the Science of Light (MPL), Erlangen — [5]Max Planck Institute of Quantum Optics (MPQ), Garching — [6]OHB System AG, Oberpfaffenhofen

Future global secure communication networks will rely on QKD with satellites. After the first successful demonstration by the Chinese satellite MICIUS, the question arises how small a satellite can be designed. We report on the progress to build a BB84 QKD payload for the nano-satellite mission QUBE. Faint laser pulses from four VCSELs at 850 nm are polarized using an array of polarizer foils and focused into a waveguide chip, which couples the four input modes into a single mode fiber. The QKD optics which will be mounted onto a 9x9 cm^2 PCB well suites as small and robust unit for the cube-satellite system. Together with a second quantum payload for CV-QKD and quantum random number generation, this mission will study the feasibility of cost effective QKD with nano-satellites in low-earth-orbits ($\sim$ 500 km altitude). In the first phase, the satellite with a planned size of only 30x10x10 cm^3 is equiped with an optical terminal (OSIRIS, aperture 20 mm) for the downlink to the optical ground station (Ø 80 cm) and will allow important tests of space capable QKD hardware.

Q 54.52 Thu 16:30 Empore Lichthof

Time-domain wavefront shaping for secure communication — •Matthias C. Velsink and Pepijn W.H. Pinkse — MESA+ Institute for Nanotechnology, University of Twente, Enschede, The Netherlands

Recently, we applied wavefront shaping techniques to implement quantum-secure readout of a physical unclonable key for authentication [1] and communication [2]. Unfortunately, spatial wavefront shaping is unsuitable for long-distance use. We therefore propose to use wavefront shaping in the time domain using a single spatial mode. We show spatiotemporal control of a pulse through a complex medium. Furthermore, we investigate a secure communication method based on physical unclonable functions in the time domain. We will report on the progress.

Reference

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[2] R. Uppu *et al.*, Asymmetric cryptography with physical unclonable keys, *Quantum Sci. Technol.* **4**, 045011 (2019).

Q 54.53 Thu 16:30 Empore Lichthof

Design and impelementation of a segmented ion trap with an integrated fiber cavity — •Omar Elshehy, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Efficient atom-photon interfaces are a basic requirement for any quantum network [1,2]. The efficiency of such interfaces has been shown to increase significantly by the use of cavities [3]. We present a segmented ion trap design for $^{40}Ca^+$ ions with an integrated fiber cavity. The trap design is optimized for the implementation of the Mølmer Sørensen gate [4] for quantum repeater applications. The fiber cavity is incorporated into the center electrodes of the trap and mounted inside intrinsically stable ferrules. Additionally, micro-structured multimode fibers are fitted for efficient photon collection. A prototype of the trap is presented along with simulation results of the trap potential. In addition, we show results of the cavity transmission and its stability, as well as microscope images of the micro-structured multimode fibers and their analysis.

[1] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)
[2] M. Bock et al., Nat. Commun. **9**, 1998 (2018)
[3] T. G. Ballance et al., Phys. Rev. A **95**, 033812 (2017)
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Q 55: Matter Wave Optics

Time: Friday 11:00–13:00 Location: a310

Q 55.1 Fri 11:00 a310

Quantum-Assisted Metrology in a Long-Baseline Matter-Wave Interferometer — •Sebastian Pedalino, Yaakov Fein, Philipp Geyer, Filip Kiałka, Stefan Gerlich, and Markus Arndt — Faculty of Physics, University of Vienna, Austria

Molecule interferometry is an intriguing tool to probe the foundations of quantum physics and it provides a useful platform for quantum assisted molecular measurements, where the interference fringes on the nanoscale can be shifted and detected with nanometer accuracy. Here we present an upgraded technique to measure molecular properties, using the Long-Baseline Universal Matter-wave Interferometer (LUMI), a near-field interferometer designed for complex massive particles. Using LUMI we have recently demonstrated quantum superposition of molecules with masses exceeding 25 kDa and consisting of up to 2000 atoms [1]. The interferometer is able to probe the quantum nature of matter with de Broglie wavelengths down to 35 fm and it has an inertial force sensitivity of 10^{-26} N. The introduction of external fields allows us to explore the electronic, optical, magnetic and structural properties of a wide range of particles. We demonstrate these capabilities by measuring the static scalar polarizability of the fullerenes C_{60} and C_{70} [2] with improved precision. We have also measured for the first time the ground state diamagnetism of isolated barium and strontium in an atomic beam.

[1] Fein, Y.Y. et al. Nat. Phys. (2019) doi:10.1038/s41567-019-0663-9
[2] Fein, Y.Y. et al. Phys. Rev. Research (2019) doi: 10.1103/PhysRevResearch.00.003000

Q 55.2 Fri 11:15 a310

Wavefront aberrations of expanding Bose-Einstein condensates — •Jan Teske and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt, D-64289, Germany

Micro-gravity experiments open new opportunities for quantum sensing technologies using cold atoms. In particular, the sensitivity of atom interferometers with Bose-Einstein condensates as a coherent atomic source benefit from long expansion times [1,2]. However, imperfections need to be considered carefully to avoid contrast loss in matter-wave interferometry.

For this purpose, we characterize the possible aberrations of an interacting condensate with optimal 3D basis functions, analogous to the wavefront decomposition in terms of Zernike polynomials in classical optics. We obtain analytical expressions for the hydrodynamic modes of an expanding Bose-Einstein condensate in the Thomas-Fermi limit [3,4] and compare them with numerical results.

[1] T. van Zoest *et al.*, Science **328**, 1540, (2010)
[2] D. Becker *et al.*, Nature **562**, 391 (2018)
[3] S. Stringari, PRL **77**, 2360 (1996)
[4] M. Fliesser *et al.*, PRA **56**, R2533(R)

Q 55.3 Fri 11:30 a310

Novel techniques for simplified cold atomic gravimeters — •Julia Pahl[1], Benjamin Wiegand[1], Bastian Leykauf[1], Klaus Döringshoff[1], Y Durvasa Gupta[1], Merle Cornelius[3], Peter Stromberger[5], Achim Peters[1,2], Markus Krutzik[1,2], and THE QUANTUS Team[1,3,4,5,6,7] — [1]HU Berlin — [2]FBH Berlin — [3]U Bremen — [4]LU Hannover — [5]JGU Mainz — [6]U Ulm — [7]TU Darmstadt

Cold atom experiments performed in practical instruments outside the lab need to satisfy strict demands on the SWaP budget (size, weight and power). In this talk, we present a technique for magneto-optical cooling and trapping of neutral Rb atoms with just a single laser [1]. Here, an agile light source, based on a micro-integrated extended cavity diode laser, is used to sequentially switch between cooling and repumping transition frequencies. We present the characterization of this alternating-frequency MOT (AF-MOT) and further discuss a simple method to determine the local gravitational acceleration by repetitive levitation of a Rb BEC with a single-frequency laser beam. Together, these techniques may be used to reduce the complexity of the laser system architecture required for cold atomic gravity sensors. This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant

number DLR 50WM1552-1557 and 50WP1432.

[1] Wiegand et al., *A single-laser alternating-frequency magneto-optical trap*, Rev. Sci. Instrum. **90, 1032202** (2019)

Q 55.4 Fri 11:45 a310

Diffraction of atomic matter-waves through crystalline materials — •Christian Brand[1], Maxime Debiossac[1], Toma Susi[1], Francois Aguillon[2], Jani Kotakoski[1], Philippe Roncin[2], and Markus Arndt[1] — [1]Universität Wien, Fakultät für Physik, A-1090 Wien, Austria — [2]Université Paris-Saclay, Institut des Sciences Moléculaires d'Orsay, F-91405 Orsay, France

In modern atom interferometers clouds of ultra-cold atoms are diffracted at laser gratings, allowing for high precision force sensing [1]. Here we discuss the complementary approach of diffracting atomic hydrogen with a velocity of up to 120.000 m/s through crystalline membranes [2]. Our analysis describes the interaction of the atomic matter-wave with the grating using TDDFT/MD simulations. Even though the simulations predict sizable coupling of the atom to the electronic system of graphene, we find a surprisingly high chance of coherent diffraction through roughly a sixth of the hexagon's area. As the grating period is 400 times smaller than in state-of-the-art nano-machined gratings [3], we predict unusual wide diffraction angles in the 10 mrad regime.

We envision this technique to give new insights into velocity-dependent effects, such as quantum friction, and for gravitational wave detection.

[1] G. M. Tino and M. A. Kasevich, Atom Interferometry (2014)
[2] C. Brand *et al.*, New J. Phys. **21** 033004 (2019)
[3] C. Brand *et al.*, Nat. Nanotechnol. **10** 845 (2015)

Q 55.5 Fri 12:00 a310

Bragg diffraction of polyatomic molecules — Christian Brand[1], Filip Kiałka[1], Stephan Troyer[1], Christian Knobloch[1], •Ksenija Simonović[1], Benjamin A. Stickler[2,3], Klaus Hornberger[2], and Markus Arndt[1] — [1]Universität Wien, Fakultät für Physik, Austria — [2]Faculty of Physics, University of Duisburg-Essen, Germany — [3]QOLS, Blackett Laboratory, Imperial College London, United Kingdom

Bragg diffraction is a widely used technique to manipulate atomic matter-waves in state-of-the art interferometers [1,2]. Here we present the first experimental realization of Bragg diffraction for complex molecules [3]. Using a thick laser grating at 532 nm, we diffract a well-collimated molecular beam and observe Bragg diffraction 0.7 m further downstream. We study this effect for the dye molecule phthalocyanine as well as for the antibiotic ciprofloxacin. The molecules are hot and may additionally absorb several photons during their passage through the laser grating. Nevertheless, we observe a pronounced angle-dependence and asymmetry in the pattern, characteristic for Bragg diffraction, illustrating the universality and robustness of the process. We can thus realize an effective mirror and large-momentum beam splitter for molecules with a momentum transfer of up to 14 $\hbar k_L$. This is an important step towards gaining control over the manipulation of functional, complex molecules.

[1] P. J. Martin *et al.*, Phys. Rev. Lett. **60** 515 (1988) [2] G. M. Tino and M. A. Kasevich, ed. *Atom Interferometry* (2014) [3] C. Brand *et al.*, submitted for publication

Q 55.6 Fri 12:15 a310

An atom interferometer testing the gravitational redshift — •Christian Ufrecht[1], Fabio Di Pumpo[1], Alexander Friedrich[1], Albert Roura[2], Christian Schubert[3], Dennis Schlippert[3], Ernst M. Rasel[3], Wolfgang P. Schleich[1,2], and Enno Giese[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm — [3]Institut für Quantenoptik, Leibnitz Universität Hannover

Light-pulse atom interferometers are based on delocalized spatial superpositions and the combination with internal-state transitions directly links them to atomic clocks. This property leads to the question whether such interferometer are sensitive to the gravitational redshift. We present a specific geometry exploiting state transitions during the interferometer sequence which provides us with this sensitivity. In contrast to Ref. [1], the proposed scheme does not rely on a superposition of internal states, but merely on transitions between them, and therefore generalizes the concept of physical atomic clocks and quantum-clock interferometry.

[1] Roura, A., Gravitational redshift in quantum-clock interferometry, ArXiv:1810.06744 (2018)

The QUANTUS project is supported by the German Aerospace Center DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant nos. DLR 50WM1556, 50WM1956

Q 55.7 Fri 12:30 a310

Atomic Raman vs. Bragg diffraction in microgravity — •Sabrina Hartmann[1], Jens Jenewein[1], Enno Giese[1], Albert Roura[2], Wolfgang P. Schleich[1,2], and the QUANTUS team[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt

The design of future atom-interferometric space missions requires making a decision about the main diffraction mechanism, Bragg [1] or Raman, at an early stage. With this goal in mind, we present a comprehensive study of Raman and Bragg diffraction in a retro-reflective geometry. This setup allows to couple to one (single diffraction) or two counter-propagating light gratings (double diffraction) [2,3] and to observe the transition from one case to the other through a change of the Doppler detuning.

We show that single Raman diffraction reaches high efficiencies for a broad parameter regime, but double Raman diffraction can only be performed efficiently in a Bragg-type regime due to additional off-resonant couplings. Moreover, broad momentum distributions experience appreciable losses in a double-diffraction scheme during a mirror pulse [4].

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1956 (QUANTUS V).

[1] *NJP* **14**, 023009 (2012).
[2] *PRA* **88**, 053608 (2013).
[3] *PRL* **116**, 173601 (2016).
[4] *arXiv*: 1911.12169 (2019).

Q 55.8 Fri 12:45 a310

Non-perturbative treatment of quasi-Bragg diffraction phases for atom interferometry — •Jan-Niclas Siemss[1,2], Florian Fitzek[2], Sven Abend[2], Ernst M. Rasel[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

Bragg diffraction is a cornerstone of light-pulse atom interferometry. High-fidelity Bragg pulses for atomic sources with a finite velocity distribution typically operate in the quasi-Bragg regime. While enabling an efficient population transfer, the diffraction phase and its dependence on the pulse parameters are currently not well characterized despite playing a key role in the systematics of the interferometer.

In our work, we formulate Bragg diffraction in terms of scattering theory. We provide an intuitive understanding of the Bragg condition and derive a unitary scattering matrix in case of adiabatic driving with Gaussian pulses. We find, that perturbations of the adiabatic solution are well described by Landau-Zener physics. Furthermore, we include the effects of linear Doppler shifts applicable to narrow atomic velocity distributions on the scale of the photon recoil of the optical lattice.

As an illustration, with our comprehensive microscopic model we study diffraction phase shift fluctuations caused by laser intensity noise affecting the sensitivity of a Mach-Zehnder atom interferometer.

This work is supported by the CRC 1227 DQmat (A05) and by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 56: Ultra-cold plasmas and Rydberg systems III (joint session A/Q)

Time: Friday 11:00–13:00 Location: b305

Invited Talk Q 56.1 Fri 11:00 b305

Coherent facilitation dynamics in Rydberg atomic lattice quantum simulators — •Paolo Pietro Mazza[1], Richard Schmidt[2,3], and Igor Lesanovsky[1,4] — [1]Institute of Theoretical physics, University of Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Strasse, 1, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [4]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

The possibility to precisely control many-body systems at the quantum level has opened the era of quantum simulators. Rydberg atoms held in optical tweezer arrays represent currently one of the most advanced simulator platforms. They are particularly suited for the implementation and study of strongly interacting spin systems. In this talk I will present results on the coherent many-body dynamics in the so-called *facilitation regime*. The focus of my talk is on the understanding of the interplay between Rydberg excitations and lattice vibrations. Using both analytical arguments and numerical simulations, I will show how vibrations of the atoms around their local equilibrium positions can alter the dispersion relation of spin excitations or even leads to their spatial localization.

Q 56.2 Fri 11:30 b305

Entanglement and Critical Dynamics in $(1+1)D$ (Rydberg) Quantum Cellular Automata — •Edward Gillman[1], Federico Carollo[1,2], and Igor Lesanovsky[1,2] — [1]School of Physics and Astronomy,University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

The study of non-equilibrium phase transitions in dissipative quantum many-body systems presents a significant challenge [1,2]. One open problem relates to the relevance of quantum correlations, and particularly entanglement, on critical physics. Recently, quantum cellular automata (QCA) * realisable in quantum simulators based on Rydberg atoms * have been shown to constitute an ideal platform for investigating such questions. In this talk we present a framework for analysing QCA with absorbing states based on projected entangled pairs states. This permits the study and quantification of the effect of entanglement on non-equilibrium dynamics and critical behaviour.

[1] F. Carollo, E. Gillman, H. Weimer, and I. Lesanovsky, Phys. Rev. Lett. 123, 100604 (2019). [2] E. Gillman, F. Carollo, and I. Lesanovsky, New Journal of Physics 21, 093064 (2019).

Q 56.3 Fri 11:45 b305

Fermi surface deformation and pairing of Rydberg-dressed fermions — •Yijia Zhou[1] and Weibin Li[1,2] — [1]School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD, UK — [2]Centre for the Theoretical Physics and Mathematics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, UK

Anisotropic long-range interactions in cold Fermi gas have attracted broad interest in studying exotic many-body physics. Previous theories and experiments on magnetic dipolar atoms have revealed distorted Fermi surface, directional zero sound, anisotropic Cooper pair and Wigner crystallisation, etc. In this work, we study the laser dressing of fermions to Rydberg p-states and d-states. Due to the higher angular momentum, the Rydberg-dressed interaction is anisotropic and long-ranged. By controlling the strength and length of the interaction, the anisotropicity is enhanced in a controlled fashion. Focusing on a single component fermion gas, we show that the strong anisotropic interaction alters the many-body ground state, such that the Fermi surface is deformed. When two fermions with opposite momentum are paired through the long-range interaction, they exhibit interesting anisotropic features. We study dependences of the anisotropic physics of the fermion gas on the laser parameter, Rydberg state, and density of atoms.

Q 56.4 Fri 12:00 b305

Precision Spectroscopy of Negative-Ion Resonances in Ultralong-Range Rydberg Molecules — •Thomas Dieterle[1], Felix Engel[1], Frederic Hummel[2], Christian Fey[4], Peter Schmelcher[2,3], Robert Löw[1], Tilman Pfau[1], and Florian Meinert[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Zentrum für optische Quantentechnologien, Fachbereich Physik, Universität Hamburg — [3]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg — [4]Max-Planck-Institute of Quantum Optics, Garching

Negative ions constitute remarkable objects that, in contrast to their neutral relatives, are very weakly bound and typically feature only few bound states. Moreover, the level structure of negative ions near the electron detachment limit also dictates the low-energy scattering of an electron with the parent neutral atom.

Here, we demonstrate how ultralong-range Rydberg molecules (ULRM) can be used as an atomic-scale system to precisely probe details of the underlying near-threshold anion states. For the first time, we present measurements of the so-far unobserved fine structure of the ^3P_J triplet of Rb^-. In addition, these measurements allow us to extract s- and p-wave scattering lengths with unprecedented precision and determine the positions of the p-wave shape resonances associated with the ^3P_J fine-structure triplet of Rb^-.

Q 56.5 Fri 12:15 b305

Engineering non-binary Rydberg interactions via electron-phonon coupling — •Filippo Maria Gambetta[1,2], Weibin Li[1,2], Ferdinand Schmidt-Kaler[3,4], and Igor Lesanovsky[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham, United Kingdom — [3]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Mainz, Germany — [4]Helmholtz-Institut Mainz, Mainz, Germany

Coupling electronic and vibrational degrees of freedom of Rydberg atoms held in optical tweezer arrays offers a flexible mechanism for creating and controlling atom-atom interactions. In our work, we demonstrate that the state-dependent coupling between Rydberg atoms and local oscillator modes gives rise to two- and three-body interactions which are controllable through the strength of the local confinement. This approach even permits the cancellation of two-body terms such that three-body interactions become dominant. We analyze the structure of these interactions on two-dimensional bipartite lattice geometries and explore the impact of three-body interactions on system ground state on a square lattice. Our work shows a highly versatile handle for engineering multi-body interactions of quantum many-body systems in most recent manifestations on Rydberg lattice quantum simulators.

Reference: F. M. Gambetta, W. Li, F. Schmidt-Kaler, I. Lesanovsky, arXiv:1907.11664

Q 56.6 Fri 12:30 b305

Engineering Rydberg-spin Hamiltonian using microwave pulse sequences — •Sebastian Geier[1], Nithiwadee Thaicharoen[1], Clement Hainaut[1], Titus Franz[1], Andre Salzinger[1], Annika Tebben[1], Carlos Brandl[1], David Grimshandl[1], Gerhard Zürn[1], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

We present engineering of general classes of spin Hamiltonians differing from the underlying Rydberg interaction Hamiltonian to experimentally study quantum spin models in an isolated environment. A system of Rydberg atoms in two distinct Rydberg states, interacting via Van der Waals or dipolar interaction, can already be mapped onto a spin system with a Heisenberg XX- and XXZ-Hamiltonian. In order to obtain access to more general classes of XYZ-Hamiltonians, we dynamically engineer terms in the given interaction Hamiltonian using global microwave pulses which couple the two different Rydberg states. With a sequence widely used in nuclear magnetic resonance that is called WAHUHA sequence, we show the ability to transform a system with XX-like interactions into an isotropic XXX-model. Mag-

netization measurements reveal that this sequence can be used to preserve the magnetization of any arbitrary initial state even if it is far-from-equilibrium. By modifying the delay time between the pulses we implement XXZ-models with different anisotropies and observe their relaxation dynamics.

Q 56.7 Fri 12:45 b305

An optogalvanic flux sensor for trace gases — •Fabian Munkes[1,2], Patrick Kaspar[1,2], Yannick Schellander[1,2], Johannes Schmidt[1,2,4], Denis Djekic[2,3], Patrick Schalberger[2,4], Holger Baur[2,4], Robert Löw[1,2], Tilman Pfau[1,2], Jens Anders[2,3], Norbert Frühauf[2,4], Edward Grant[5], and Harald Kübler[1,2] — [1]5. Physikalisches Institut — [2]Center for Integrated Quantum Science and Technology — [3]Institut für Intelligente Sensorik und Elektrotechnik — [4]Institut für Großflächige Mikroelektronik — [5]Department of Chemistry University of British Columbia

We demonstrate the applicability of a new kind of gas sensor based on Rydberg excitations. From a gas mixture the molecule in question is excited to a Rydberg state. By succeeding collisions with all other gas components this molecule becomes ionized and the emerging electron can be measured as a current, which is the clear signature of the presence of this particular molecule. As a first test we excite Alkali Rydberg atoms in an electrically contacted vapor cell [1,2] and demonstrate a detection limit of 100 ppb to a background of N_2. For a real life application, we employ our gas sensing scheme to the detection of nitric oxide at thermal temperatures and atmospheric pressure [3]. We show first results of cw spectroscopy of the $A\,^2\Sigma^+ \leftarrow X\,^2\Pi_{1/2}$ transition in NO.

[1] D. Barredo, et al., *Phys. Rev. Lett.* **110**, 123002 (2013)
[2] J. Schmidt, et al., SPIE **10674** (2018)
[3] J. Schmidt, et al., *Appl. Phys. Lett.* **113**, 011113 (2018)

Q 57: Quantum Information (Quantum Repeater)

Time: Friday 11:00–13:00 Location: e001

Group Report Q 57.1 Fri 11:00 e001

Resource Efficient One-way Quantum Repeater — •Tim Schröder — Humboldt-Universität zu Berlin — Ferdinand-Braun-Institut, Berlin

Towards the realisation of a 'one-way' quantum repeater, we show progress on theoretical concepts and experimental implementation. While to date 'one-way' quantum repeater proposals rely on a relatively large number of stationary and flying qubit resources, we introduce a scheme that is based on photonic tree cluster states and that requires only one single photon emitter and two ancilla qubits per communication node, reducing the resource requirements by orders of magnitude. We analyse achievable quantum communication rates for different repeater parameters, and simulate that about 70 kHz quantum bit rate over a distance of 1000 km can be achieved. Moreover, we show that the implementation of such a quantum repeater is almost accessible with today's technology, and we introduce physical modules that allow for its experimental realisation. Towards the implementation of such modules we show our experimental progress with spin-photon interfaces based on defect centres in diamond nanostructures.

Q 57.2 Fri 11:30 e001

Towards a Suburban Quantum Network Link — •Tim van Leent[1], Robert Garthoff[1], Matthias Bock[2], Kai Redeker[1], Florian Fertig[1], Derya Taray[1], Matthias Seubert[1], Wei Zhang[1], Wenjamin Rosenfeld[1,3], Christoph Becher[2], and Harald Weinfurter[1,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — [2]Fachrichtung Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Quantum repeaters will allow scalable quantum networks, which is essential for large scale quantum communication and distributed quantum computing. Yet, still missing on the road towards a quantum repeater, is to achieve entanglement between quantum memories over long distances.

Here we present results demonstrating distribution of atom-photon entanglement at the telecom wavelength over 20 km optical fiber with a fidelity of >79% [1]. For this purpose, we use polarization-preserving quantum frequency conversion, where the photon at 780 nm is mixed with a strong pump field at 1600 nm inside a nonlinear waveguide crystal. Implementing frequency conversion for the second atom and employing the entanglement swapping protocol [2] in the telecom will enable the next important milestone, i.e., generating atom-atom entanglement on a suburban scale.

[1] T. van Leent et al., arXiv:1909.01006 (2019)
[2] W. Rosenfeld et al., Phys. Rev. Lett. **119**, 010402 (2017)

Q 57.3 Fri 11:45 e001

Optimized cavity-enhanced down-conversion source in interferometric configuration — •Jan Arenskötter, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

An efficient resource of entanglement in atom-photon-based quantum networks are polarization-entangled photon pairs generated by type-II spontaneous parametric down-conversion (SPDC). Previously, we presented a cavity-enhanced SPDC source in interferometric configuration, which is tailored to match the $P_{3/2}$ to $D_{5/2}$ transition of $^{40}Ca^+$ at 854 nm [1].

Here we show improvements and optimizations of this photon pair source. We changed the cavity geometry from a bow-tie to a triangle configuration which resulted in a shortening of the cavity length. By this we improve the scaling of the signal-to-background ratio due to an increased bandwidth of the photons. The photons coming from the new source are non-degenerate but still show polarization entanglement with a fidelity of at least 97.9% to the Ψ^--Bell state. The locking scheme of the cavity and the interferometer have also been improved for better signals and higher stability.

[1] DPG Verhandlungen Q2.7, Mainz 2017

Q 57.4 Fri 12:00 e001

A passive, heralded quantum memory with crossed optical fiber cavities — •Dominik Niemietz[1], Manuel Brekenfeld[1], Joseph D. Christesen[1,2], and Gerhard Rempe[1] — [1]MPQ, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]NIST, Boulder, Colorado 80305, USA

The impossibility to clone quantum information renders quantum communication secure, but also prevents quantum information from being amplified, causing processes that are subject to losses become probabilistic. In many cases, finite success probabilities can be coped with a herald [1] that indicates the successful completion of a process without touching the underlying quantum information. This applies, in particular, to the propagation of photons in quantum networks [2] where photon loss in optical fibers can be remedied using quantum repeaters [1]. In this talk, we present a promising candidate for a node in such a network: A heralded quantum memory for photonic polarization qubits based on single rubidium atoms trapped at the crossing point of two optical fiber cavities, one for the qubit, the other for the herald. Our high-fidelity quantum memory features fully passive storage, requiring neither amplitude- and phase-critical control fields nor error-prone feedback loops. With these properties, our system can be an important contribution to the current quest for a quantum repeater and for the realization of hybrid quantum systems.

[1] Briegel, Dür, Cirac and Zoller, Phys. Rev. Lett. **81**, 5932-5935 (1998)
[2] Ritter et al., Nature **453**, 1023-1030 (2012)

Q 57.5 Fri 12:15 e001

Space-borne quantum memories for quantum communication and fundamental physics: prospects and challenges — •Mustafa Gündoğan[1], Dennis Rätzel[1], Janik Wolters[2], Daniel Oi[3], and Markus Krutzik[1,4] — [1]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, 12489 Berlin, Germany — [3]SUPA Department of Physics, University of Strathclyde, John Anderson Building, Glasgow, G4 0NG, UK — [4]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

Storing quantum information in material systems, i.e. in quantum memories (QM), is a key requirement for quantum information tasks in which probabilistic events have to be synchronized. Among the first applications of QMs is to extend the distance over which a quantum entangled state could be shared as nodes in a quantum repeater. In this work we compare performances of space-based quantum communication architectures without and with the help of QMs and quantify advantages that are brought by QMs.

Another potential use of space-based QMs is to store quantum information in curved space-times for extended period of times. In this context, we discuss novel experiments that would be enabled by QMs to probe general relativistic proper time in quantum mechanics.

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 50WM1958.

Q 57.6 Fri 12:30 e001

Stabilization of a high-finesse cavity with an Erbium doped crystal in a closed-cycle cryostat — •Alexander Ulanowski[1], Benjamin Merkel[1], and Andreas Reiserer[1,2] — [1]MPI of Quantum Optics, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, München, Germany

Cryogenic optical resonators are promising for the implementation of quantum repeaters based on dopants in solid-state systems. Due to mechanical vibrations in a closed-cycle cryostat, such resonators require elaborate passive and active stabilization. The presence of mechanical resonances and anti-resonances in the resonator mount can however limit the bandwidth of active feedback when using ordinary controllers, e.g. a proportional-integral-derivative controller (PID).

We overcome this limitation by using a Finite Impulse Response (FIR) filter realized digitally on a field-programmable gate array device to cancel out these mechanical resonances and increase the unity gain frequency. [1] In combination with passive stabilization of our high-finesse resonator ($\mathcal{F} \approx 10^5$), we achieve a sub-pm stability at a temperature of 2K. This allows us to observe emission of erbium ions, doped into a crystal that is embedded in the resonator, with a Purcell enhancement factor of several hundreds.

[1] Ryou and Simon, Rev. Sci. Instrum. 88, 013101 (2017)

Q 57.7 Fri 12:45 e001

Resonant spectroscopy of erbium dopants in silicon nanophotonic waveguides — •Florian Burger[1,2,3], Lorenz Weiss[1,3], Andreas Gritsch[1], Johannes Früh[1,4], Laura Zarraoa[1,5], and Andreas Reiserer[1,3] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Technical University of Munich, Germany, Department of Physics — [3]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, Germany — [4]University of Applied Sciences Munich, Germany — [5]Technical University of Denmark, Copenhagen, Denmark

Silicon photonics has developed into a mature technological platform that allows for rapid development cycles using standardized tools. Integrating coherent optical emitters into this platform would open unique possibilities towards implementing a scalable platform for quantum repeaters. In this context, we explore the use of erbium dopants that feature a coherent optical transition at a wavelength close to 1.5 μm, where the loss in both optical fibers and silicon waveguides is minimal. Previous experiments, targeted at laser development, used high implantation doses and off-resonant excitation by a focused laser. In contrast, the use of low-loss nanowire waveguides allows us to perform resonant spectroscopy. At cryogenic temperatures, we observe narrow optical resonances, suggesting that the erbium dopants are integrated into the crystal lattice at well-defined sites. We will present the current status of the experiment and our progress towards coherent control of individual erbium spins in silicon by embedding them into photonic crystal waveguides and cavities.

Q 58: Quantum gases (Bosons) V

Time: Friday 11:00–13:00 Location: e214

Group Report Q 58.1 Fri 11:00 e214

Thermally condensing photons into a coherently split state of light — •Christian Kurtscheid[1], David Dung[1], Erik Busley[1], Frank Vewinger[1], Achim Rosch[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77, 50937 Cologne, Germany

Techniques to control the quantum state of light play a crucial role in a wide range of fields, from quantum information science to precision measurements. While for electrons in solid state materials complex quantum states can be created by mere cooling, in the field of optics manipulation and control currently builds on non-thermodynamic methods. Using an optical dye microcavity, we have split photon wavepackets by thermalization within a potential with two minima subject to tunnel coupling [1]. Even at room temperature, photons condense into a quantum-coherent bifurcated ground state. Fringe signals upon recombination show the relative coherence between the two wells, demonstrating a working interferometer with the non-unitary thermodynamic beamsplitter. This energetically driven optical state preparation opens up an avenue for exploring novel correlated and entangled optical manybody states.

[1] C. Kurtscheid, D. Dung, E. Busley, F. Vewinger, A. Rosch, M. Weitz, *Science* **366**, 894 (2019).

Q 58.2 Fri 11:30 e214

Multimode cavity QED description of photonic Bose–Einstein condensation — •David Steinbrecht[1], Robert Bennett[1,2], and Stefan Yoshi Buhmann[1,2] — [1]University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Bose–Einstein condensation of photons has recently been observed experimentally [1]. In a laser-driven, dye-filled cavity photons thermalise to the dye temperature by multiple absorption and re-emission processes and subsequently undergo Bose–Einstein condensation. We use an open quantum systems approach [2] to describe the molecule-light interactions. Allowing for mechanisms to lift the degeneracy between cavity modes of different polarisations, we predict symmetry-breaking effects [3].

In this talk we will give a brief overview of the model and show solutions to the rate equations for the occupation numbers of the cavity modes. Condensation occurs when the pumping rate surpasses a critical threshold and the lowest-energy state becomes macroscopically occupied.

[1] J. Klaers et al., Nature 468, 545-548 (2010).

[2] P. Kirton and J. Keeling, Phys. Rev. A 91, 033826 (2015).

[3] R. Bennett, Y. Gorbachev, S. Y. Buhmann, arXiv quant-ph:1905.07590.

Q 58.3 Fri 11:45 e214

Nonequilibrium density wave order in driven atom-cavity system — •Christoph Georges, Hans Kessler, Phatthamon Kongkhambut, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

Competing Phases and their driving are subject of interest in the field of light-induced phase in heavy-fermion systems [1] such as in light-induced superconductivity. However, because of their complex nature, materials like cuprates are delicate to theoretical grasp. Recent efforts lead to quantum gas experiments emulating simplified models for solid-state phenomena.

An ultracold gas of atoms inside a high-finesse optical cavity is one example of a versatile platform for exploring non-equilibrium phenomena and dynamical driven phase transitions in many-body systems [2]. We observe the formation of a new competing non-equilibrium density wave order in a resonantly driven Bose-Einstein Condensate coupled to the light field of a high finesse cavity. Without driving, the system organizes in a density wave that supports Braggscatting into the cavity and stabilizes itself. Meanwhile, when driving is applied, it suppresses this density wave, and a non-equilibrium density wave can be excited. This new density wave does not support further scattering into the cavity. We report on this new emerging phase in respect of driving parameters and its temporal evolution.

[1] Kogar et al. Nat. Phys. s41567-019-0705-3 (2019)

[2] C. Georges et al. Phys. Rev. Lett. 121, 220405 (2018)

Q 58.4 Fri 12:00 e214

Continuous feedback on a quantum gas coupled to an optical cavity — •Rodrigo Rosa-Medina, Katrin Kroeger, Nishant Dogra, Marcin Paluch, Fabian Finger, Francesco Ferri, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Ultracold atoms constitute a highly versatile platform to study quantum many-body dynamics and phase transitions. In our experiment, we realize a driven-dissipative Dicke model by coupling a ^{87}Rb Bose-Einstein condensate (BEC) to a high-finesse optical cavity. The BEC is transversally pumped by a standing wave laser and photons are off-resonantly scattered into the cavity. Above a critical pump power, the system undergoes a phase transition into a superradiant state characterized by a self-organized modulation of the atomic density. Photons leaking out from the cavity provide natural channel for real-time, weak measurements of the system's state.

We present the experimental realization of an active feedback scheme within the self-organized phase. By acting on the intensity of the pump field, we stabilize the mean intra-cavity photon number (n_{ph}). Our micro-controller based feedback architecture can sustain a wide range of constant photon numbers both deep inside the self-organized state ($n_{\mathrm{ph}} > 20$) and close to the phase transition ($n_{\mathrm{ph}} < 0.2$) for up to 4 seconds. Thereby, we can approach the phase transition with a high degree of control. Our experiments pave the way towards the realization of exotic many-body phases through tailored feedback schemes, such as limit cycles driven by delayed feedback or Floquet time crystals.

Q 58.5 Fri 12:15 e214

Crystalline droplets with emergent color-charge in multimode optical cavities — •Petr Karpov[1,2] and Francesco Piazza[1] — [1]Max Planck Institute for the Physics of Complex Systems, Noethnitzer Str. 38, Dresden 01187, Germany — [2]National University of Science and Technology “MISiS”, Moscow, Russia

In my talk I'll describe a novel type of droplet which carries an emergent color-charge. The droplet exists in either a thermal gas regime or in a form of BEC, where the finite-range bounding interaction is provided by a multimode optical cavity. The sign-changing nature of the cavity-mediated interaction endows droplets with two types of charges (i.e. sublattices) governing their mutual interactions: attractive for equal colors and repulsive otherwise. The droplets are formed via first-order phase transition which gives an alternative route to the non mean-field type of self-organisation phase transitions proposed in [1]. The droplets represent a new type of effective mesa-“particles” showing a viscous glassy dynamics which can be non-destructively monitored by imaging the amplitude and the phase of the scattered light.

[1] S. Gopalakrishnan, B. Lev, and P. Goldbardt, Nat. Phys. 5, 845 (2009).

Q 58.6 Fri 12:30 e214

Compressing the Phase Space Density of Light by Thermalization in a Dye-Filled Microcavity — •Erik Busley, Christian Kurtscheid, Fahri Öztürk, David Dung, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

A two-dimensional photon gas confined in a dye-filled optical microcavity can exhibit both thermalization and – above a critical particle number – Bose-Einstein condensation, as shown in earlier work of our group [1, 2]. The used short spacing of the two curved mirrors of the microcavity makes the system formally equivalent to a two-dimensional, harmonically trapped one of massive bosons, where thermalization of the photon gas is achieved by repeated absorption and emission cycles on the dye molecules.

A spectral redistribution comes along with a spatial redistribution of photons. Here we investigate phase space compression of the photon gas below the threshold to Bose-Einstein condensation from the thermalization, as expected from an effective cooling of the photon cloud to room temperature in the trapping potential. The variation of the final phase space density is studied for different mirror reflectivity profiles and dye spectra. The current status of the experiment, along with a simple numerical model will be reported.

[1] J. Klärs et al., *Nature* **468**, 545 (2010)
[2] J. Klärs et al., *Nat. Phys.* **6**, 512 (2010)

Q 58.7 Fri 12:45 e214

Dimensional Crossover of Photon Bose-Einstein Condensates — •Enrico Stein and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

In recent years the phenomenon of equilibrium Bose-Einstein condensation (BEC) of photons has been studied extensively also within the realm of non-equilibrium condensation. At its core this system consists of a dye solution filling the microcavity in which the photons are trapped. Due to cyclic absorption and reemission processes of photons the dye leads to a thermalisation of the photon gas at room temperature and finally to its Bose-Einstein condensation. Because of a non-ideal quantum efficiency, those cycles yield in addition a heating of the dye solution, which results in an effective photon-photon interaction [1]. This talk focuses on the theoretical description of a dimensional crossover from a two-dimensional photon BEC to a one-dimensional photon gas. To this end we extend the semiclassical mean-field equations for a photon BEC [2] by including the matter degrees of freedom. Our special focus lies on the effect of the retarded photon-photon interaction on the dimensional crossover, which we study for a anisotropic box potential. Finally, we characterise the steady state of the resulting one-dimensional photon gas.

[1] J. Klärs, J. Schmitt, T. Damm, F. Vewinger, and M. Weitz, Appl. Phys. B **105**, 17 (2011)

[2] E. Stein, F. Vewinger, and A. Pelster, New J. Phys. **21**, 103044 (2019)

Q 59: Ultra-cold atoms, ions, and BEC VII (joint session A/Q)

Time: Friday 11:00–13:00 Location: f303

Invited Talk Q 59.1 Fri 11:00 f303

Interaction-induced lattices for bound states: Designing flat bands, quantized pumps and higher-order topological insulators for doublons — •Grazia Salerno, Giandomenico Palumbo, Nathan Goldman, and Marco Di Liberto — Center for Nonlinear Phenomena and Complex Systems,Universit *e Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium

Bound states of two interacting particles moving on a lattice can exhibit remarkable featuresthat are not captured by the underlying single-particle picture. Inspired by this phenomenon, weintroduce a novel framework by which genuine interaction-induced geometric and topological effectscan be realized in quantum-engineered systems. Our approach builds on the design of effectivelattices for the center-of-mass motion of two-body bound states, which can be created throughlong-range interactions. This general scenario is illustrated on several examples, where flat-bandlocalization, topological pumps and higher-order topological corner modes emerge from genuineinteraction effects. Our results pave the way for the exploration of interaction-induced topologicaleffects in a variety of platforms, ranging from ultracold gases to interacting photonic devices.

Q 59.2 Fri 11:30 f303

Spectroscopy of interorbital dimers and pair states in Ytterbium-171 — •Oscar Bettermann[1,2], Nelson Darkwah Oppong[1,2], Giulio Pasqualetti[1,2], Luis Riegger[1,2], Immanuel Bloch[1,2], and Simon Fölling[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Ludwig-Maximilians-Universität, Munich, Germany

An outstanding feature of alkaline-earth-(like) atoms is the existence of a metastable excited electronic state connected to the ground state via an ultranarrow "clock" transition. The interactions between atoms in the different electronic states are governed by the molecular interaction potentials between the atoms and the bound states formed inside these potentials.

Here, we report on the direct production and spectroscopy of the least bound state in Ytterbium-171 and characterization of the interactions between atoms in different electronic states. The dimers are produced by direct single-photon photoassociation via the clock line, in a deep three-dimensional optical lattice. In strong contrast to the shallow bound state present in Ytterbium-173, we find a much larger binding energy, with a much smaller molecular wavefunction therefore largely independent of the external potentials. We also show that the free-to-bound transition can be made insensitive to the depth of the trapping potential, an important aspect in the realization of optical molecular clocks.

Q 59.3 Fri 11:45 f303

A subradiant two-dimensional atomic array forming an optical mirror — •David Wei[1], Jun Rui[1], Antonio Rubio-Abadal[1], Simon Hollerith[1], Kritsana Srakaew[1], Simon Evered[1], Immanuel Bloch[1,2,3], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, München, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany

When quantum emitters are positionally structured on sub-wavelength scales, photon-mediated dipole-dipole interactions can strongly alter the spectral and directional radiative response. Tightly trapped atoms in optical lattices, only coupled to the electromagnetic vacuum, constitute ideal dipolar emitters to study such cooperative behaviour.

In our experiment, we probe the collective properties of a two-dimensional square array of atomic dipoles by performing spectroscopic absorption and reflection measurements. We directly observe considerably subradiant response and demonstrate that the array acts as a reflective mirror formed by a single mono-layer of a few hundred atoms. By varying the atom density within the array, we are able to control the influence of the dipolar interactions. By introducing positional disorder in the atomic ensemble, we analyze the role of the array structure. Its importance is emphasized by dynamically breaking and restoring the order using atomic Bloch oscillations to control the reflectivity of the atomic mirror.

Q 59.4 Fri 12:00 f303

State-dependent optical lattices for the clock states of strontium — •Annie Jihyun Park[1], Andre Heinz[1], Trautmann Jan[1], Neven Santic[1], Sergey G Porsev[2,3], Marianna S Safronova[2,4], Immanuel Bloch[1,5], and Sebastian Blatt[1] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]U. Delaware, Newark, USA — [3]Petersburg Nuclear Physics Institute, Gatchina, Russia — [4]JQI, NIST and U. Maryland, College Park, USA — [5]LMU, Munich, Germany

We demonstrate state-dependent optical lattice for the clock states in strontium at the tune-out wavelength for the 1S0 ground state, where its dipole polarizability vanishes. Using a novel spectroscopic method, we measure 689.222225(14) nm for this tune-out wavelength in Sr-88, one of the most precise and accurate measurements of a tune-out wavelength to date. Since our method does not require quantum degenerate gases, it is also suited for measuring tune-out wavelengths for atoms in metastable states, molecules, fermionic species and trapped ions. Furthermore, we measure the polarizability of the excited 3P0 clock state at the tune-out wavelength using high-resolution clock spectroscopy, demonstrating the first excited state polarizability measurement in an alkaline-earth-metal atom. In a proof-of-principle experiment, we trap 3P0 atoms in a one-dimensional optical lattice at the tune-out wavelength. Our measurements benchmark state-of-the-art atomic structure calculations and pave the way for state-dependent manipulations of strontium atoms for high-fidelity quantum simulations and quantum computation schemes.

Q 59.5 Fri 12:15 f303

Atom number stabilization with single-atom precision — Andreas Hüper[1], Cebrail Pür[1], •Mareike Hetzel[1], Jiao Geng[1], Mick Kristensen[2], Jan Arlt[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut for Fysik og Astronomi, Aarhus Universitet, Denmark

The preparation and evaluation of quantum states for optimal entanglement-enhanced metrology relies on an accurate determination of the number of atoms. We present an accurate fluorescence detection of atoms trapped in a miniature magneto-optical trap. We utilize the accurate atom number detection for a number stabilization of a laser-cooled atomic ensemble. For a target ensemble size of seven atoms prepared on demand, we achieve a 92 % preparation fidelity and reach number fluctuation 18 dB below the shot noise level using real-time feedback on the magneto-optical trap.

Q 59.6 Fri 12:30 f303

Continuous measurement of a quantum driven top — •Jessica Eastman[1], Stuart Szigeti[2], Joseph Hope[2], and André Carvalho[3] — [1]Imperial College London, London, UK — [2]Australian National University, Canberra, Australia — [3]Q-CTRL, Australia

The need to understand many-body quantum chaos is motivated by a growing area of research with connections to topics such as random unitaries, holographic duality and information scrambling in black holes, nonequilibrium thermodynamics and quantum sensing. We theoretically investigate the effect that continuous weak measurement can have on the emergence of chaos in many-body quantum systems by looking at a system that can be easily realisable in ultra cold atom experiments: the Quantum driven top. The corresponding classical system in this case is a closed system with no dissipation. By adding weak coupling to a measurement device, we introduce decoherence to the system.

Q 59.7 Fri 12:45 f303

Bulk topological proximity effect in multilayer systems — Jaromir Panas[1], •Bernhard Irsigler[1], Jun-Hui Zheng[1,2], and Walter Hofstetter[1] — [1]Goethe-University Frankfurt, Germany — [2]NTNU, Trondheim, Norway

We investigate the bulk topological proximity effect in multilayer lattice systems. We show that one can introduce topological properties into a system composed of multiple trivial layers by coupling to a single nontrivial layer described by the Haldane model. This phenomenon depends not only on the number of layers but also on their arrangement, which can lead to the emergence of dark states in multilayer systems. The response of a trivial system to the proximity of a topological insulator appears to be highly nonlocal, in contrast to the proximity effect observed in context of superconductivity. We also find a range of parameters where our system is semimetallic with features similar to the ones observed in three-dimensional topological states. This is promising from the perspective of bridging two- and three-dimensional topologically protected states of matter.

Q 60: Quantum Effects (Cavity QED)

Time: Friday 11:00–13:00 Location: f442

Q 60.1 Fri 11:00 f442

Ab initio few-mode theory — •Dominik Lentrodt and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Few-mode models, such as the Jaynes-Cummings model and its many generalizations, have been an indispensable tool in studying the quantum dynamics of light-matter interactions. In particular in cavity and circuit QED these models have been tremendously successful and have been employed in combination with the famous input-output formalism to compute, for example, scattering observables. Recently, however, extreme regimes, such as the overlapping modes and ultra-strong coupling regime, have become accessible in various experimental platforms. In these regimes the applicability of input-output models has been debated. In this talk, we will present an ab-initio method to construct few-mode Hamiltonians that apply even in such extreme regimes [1]. Our theory extends the validity range of Jaynes-Cummings type models without abandoning their conceptual and computational simplicity. In a nutshell, our scheme provides a way to extract relevant degrees of freedom from a structured environment in an open quantum system, allowing to construct a non-perturbative expansion in the mode number. We will outline implications for a broad range of platforms, including quantum optics with non-Hermitian degeneracies [2], multi-mode strong coupling [3], and quantum scattering theory in general [4]. [1] Lentrodt & Evers (2018) arXiv:1812.08556, [2] Özdemir et. al. *Nat. Mat.* **18** 783 (2019), [3] Krimer et. al. *Phys. Rev. A* **89**

033820 (2014), [4] Rotter & Gigan *Rev. Mod. Phys.* **89** 015005 (2017)

Q 60.2 Fri 11:15 f442

Multi-atom scaling of light-matter interactions in a fiber-coupled cavity — •Fabian Spallek and Stefan Yoshi Buhmann — Physikalisches Institut, Freiburg i.Br., Germany

The coupling of tightly controlled single resonant photons and transitions in neutral atoms in open fiber cavities allows for strongly coupled, highly coherent collective light-matter interaction rates. They could provide a high cooperativity, high-bandwidth, fiber-coupled channel for photonic interfaces such as quantum memories and single-photon sources [1]. We use methods from macroscopic Quantum Electrodynamic (QED) and Cavity-QED to investigate how the light-atom interactions depend on the positioning of the atoms with respect to the mode, which can be controlled by an optical dipole trap [2][3]. In this way, we can predict the collective Rabi frequency and the quantitative scaling of the observed Purcell enhancement for a given collection of trapped atoms. Similarities of these collective effects to superradiance in other settings are discussed.

[1] J. Gallego, W. Alt, T. Macha, M. Martinez-Dorantes, D. Pandey, and D. Meschede, *Strong Purcell Effect on a Neutral Atom Trapped in an Open Fiber Cavity*, Phys. Rev. Lett. 121, 173603, (2018)
[2] S. Esfandiarpour, H. Safari, R. Bennett, and S. Y. Buhmann, *Cavity-QED Interactions of Two Correlated Atoms*, J. Phys. B: At. Mol. Opt. Phys. 51, 094004, (2018)
[3] S. Esfandiarpour, H. Safari, and S.Y . Buhmann, *Cavity-QED Interactions of Several Atoms*, J. Phys. B: At. Mol. Opt. Phys. 52, 085503, (2019)

Q 60.3 Fri 11:30 f442

The coupling of free-electrons with whispering-gallery modes — •Ofer Kfir[1], Hugo Lourenço-Martins[1], Gero Storeck[1], Murat Sivis[1], Tyler Harvey[1], Tobias Kippenberg[2], Armin Feist[1], and Claus Ropers[1] — [1]University of Göttingen, Göttingen, Germany — [2]EPFL, Lausanne, Switzerland

Electron microscopes are a ubiquitous tool for nanoscopic characterization, providing for resolutions down to the atomic scale. In recent years, classical light fields are being employed for quantum-state manipulations of electron beams, enabling acceleration (1), attosecond electron pulses (2) and light-induced phase retarders (3). However, the typically weak coupling between electrons and photons requires strong fields to produce meaningful effects. Here we show theoretically and experimentally that whispering-gallery modes (WGM) in microresonators can push electron-photon interactions towards the strong coupling regime. Our experiment (4) shows that WGMs have an enhanced interaction with electrons, manifested in hundreds of electron-energy sidebands. We discuss a roadmap to approach a measureable entanglement between cavity-photons and free-electrons (5), and predict the properties of such a state. In the future, complex optical states may be imprinted on electron beams, providing for optical spectroscopy with spatial resolution at the atomic scale.

1. E. A. Peralta, et al., Nature. 503, 91 (2013). 2. K. E. Priebe, et al., Nat. Phot. 11, 793 (2017). 3. O. Schwartz, et al., Nat. Meth. 16, 1016 (2019). 4. O. Kfir, et al., arXiv:1910.09540 (2019). 5. O. Kfir, Phys. Rev. Lett. 123, 103602 (2019),

Q 60.4 Fri 11:45 f442

Monolithic Fiber Fabry-Perot Cavities with improved mode matching. — •Madhavakkannan Saravanan, Carlos Saavedra Salazar, Deepak Pandey, Hannes Pfeifer, Wolfgang Alt, and Dieter Meschede — Institute of Applied Physics, University of Bonn, Germany

Fiber Fabry-Perot cavities (FFPCs) are an established tool to optically interface atomic, molecular or solid-state systems. However, the stability and, in the case of long cavities, the mode matching of the guided fiber mode to the FFPCs remain challenging.

To overcome these limitations we use a monolithic FFPC design that combines high passive stability with tunability across a free spectral range. Improving the mode matching to a guided fiber mode can be accomplished using stacks of different fiber types such as single-mode, multi-mode and graded-index fibers [1]. We show how the fabrication of these assemblies using splicing of fibers with different material characteristics as well as cleaving with micrometer precision can be accomplished. The quality of fabricated assemblies is assessed by microscope-imaging of the out-coupled fiber mode.

The combination of these techniques has the potential to extend the range of applications for FFPCs to e.g. frequency filters, cavity ring-down spectroscopy or cavity-QED with ions.

[1] Gulati et al., Sci Rep 7, 5556, (2017).

Q 60.5 Fri 12:00 f442

Benchmarking the coupling of single photon emitters to optical resonators — •Gregor Bayer[1], Stefan Häussler[1,2], Igor Aharonovich[3], David Hunger[4], and Alexander Kubanek[1,2] — [1]Institut für Quantenoptik, Universität Ulm — [2]Center for Integrated Quantum Science and Technology — [3]School of Mathematical and Physical Sciences, University of Technology Sydney — [4]Physikalisches Institut, Karlsruher Institut für Technologie

Solid-state based quantum emitters offer a promising platform for various quantum technology applications like quantum repeaters. We present a light matter interface based on a high quality microcavity and compare single photon emitting defects in tailored host matrices with the focus on overcoming the remaining challenges for a scalable use in form of a low rate of coherent photons, poor extraction efficiency out of the host material and low quantum yield. We investigate the system's scattering losses to estimate the possible Purcell enhancement in high Q resonators.

Q 60.6 Fri 12:15 f442

Single-Photon Switching: A Single Molecule Strongly Coupled to a Microcavity — •André Pscherer, Manuel Meierhofer, Daqing Wang, Hrishikesh Kelkar, Diego Martín-Cano, Stephan Götzinger, and Vahid Sandoghdar — Max-Planck-Institut für die Physik des Lichts, Erlangen, Germany

Nonlinear light-matter interactions usually involve macroscopic materials and high intensities, often involving pulsed lasers. Considering the intrinsic optical nonlinearity of atoms and molecules, however, one can imagine performing operations such as switching by using single quantum emitters and single photons. We show that single organic molecules embedded in a solid nanoscopic matrix can indeed provide access to this realm when coupled to a Fabry-Pérot cavity with a very small mode volume. We demonstrate vacuum Rabi oscillations, single-photon switching and four-wave mixing at the level of single photons in the strong coupling regime [1].

[1] A. Pscherer, *et al.*, *in preparation.*

Q 60.7 Fri 12:30 f442

Continuous Quantum Light from a Dark Atom: Theory — •Bo Wang[1], Christopher Ianzano[1], Nicolas Tolazzi[1], Celso Villas-Boas[2], and Gerhard Rempe[1] — [1]Max Planck Institute for Quantum Optics — [2]Universidade Federal de Sao Carlo

Single photons can be generated from a single atom strongly coupled to an optical cavity via a stimulated Raman adiabatic passage between two atomic ground states [1]. During the generation of the photon, the atom stays within the dark state of electromagnetically induced transparency(EIT) avoiding spontaneous decay from the excited state. In contrast to this well-known scenario, here we present the theoretical result to generate quantum light continuously from an atom in the dark state. A coherent coupling is added between the atomic ground states to allow the coherent generation of multiple photons. This would usually result in the destruction of the dark state and the reappearance of spontaneous decay. However, the dark states of the strongly coupled cavity EIT result from the interference between two atomic ground states entangled with different photonic states [2]. Such dark states are preserved from the local coupling that is applied only within the atomic Hilbert space. Additionally, the nonlinearity of the system allows us to control the quantum fluctuations of the generated light via a quantum Zeno effect.

[1]Kuhn, A et al., Phys. Rev. Lett. 89(6), 067901 (2002).
[2]Souza, J.A. et al., Phys. Rev. Lett. 111, 113602 (2013).

Q 60.8 Fri 12:45 f442

Continuous Quantum Light from a Dark Atom: Experiment — •Christopher Ianzano[1], Nicolas Tolazzi[1], Bo Wang[1], Celso Villas-Boas[2], and Gerhard Rempe[1] — [1]Max Planck Institute for Quantum Optics — [2]Universidade Federal de Sao Carlo

Cavity QED has been shown to be a powerful tool in atomic physics and quantum optics experiments. In a conventional lambda-type cavity EIT system, a ladder of dark states that are harmonic in intracavity photon number is generated. By Closing the lambda system with a field (or in our case a Raman pair) that directly couples the two ground states, transitions are driven between these dark states. We demonstrate experimentally a four-wave-mixing scheme where the field emitted from the cavity shifts frequency as the sum-difference frequency of the three input fields. Additionally, the output photon statistics are analyzed as a function of input field strengths, and a Zeno-blockade effect is observed. For weak driving, the system is constrained very well to the ground state and the first dark state, but as the driving strength is increased, the blockade is lifted and higher photon number dark states are accessed. Additionally, because the transitions driven are all dark states, the atomic excited state is not populated. In the high-driving limit, we show a field that is increasingly coherent without significantly increasing the average photon number, allowing us to tune the output photon statistics without changing the intracavity field.

Q 61: SYCM: Contributed talks for the Symposium Hot topics in cold molecules: From laser cooling to quantum resonances

Time: Friday 14:00–15:15 Location: e415

Q 61.1 Fri 14:00 e415

Towards laser cooling and trapping of AlF molecules — •Simon Hofsäss[1], Maximilian Doppelbauer[1], Sebastian Kray[1], Jesùs Pérez-Ríos[1], Boris Sartakov[2], Gerard Meijer[1], and Stefan Truppe[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Faradayweg 4-6

We have recently identified the aluminium monofluoride (AlF) molecule as an excellent candidate for laser cooling and trapping at high densities and measured the detailed energy level structure of the electronic states relevant for these processes[1].

Here we report the characterization of a cryogenic buffer gas molecular beam of AlF that will be used to load a magneto optical trap (MOT). Spectroscopic techniques are applied to determine properties of the beam source such as molecular flux, velocity distribution and beam divergence. We investigate the optical cycling process on the rotationally closed Q lines of the main cooling transition and compare the measurements to a theoretical model.

[1] Truppe et al., Phys. Rev. A 100, 052513 (2019)

Q 61.2 Fri 14:15 e415

Towards sympathetic cooling of the ultracold SrF molecule — •Maciej Kosicki[1], Masato Morita[2], Piotr Zuchowski[1], and Timur Tscherbul[2] — [1]Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń, Poland, 87-100 — [2]Department of Physics, University of Nevada, Reno, NV, 89557, USA

Sympathetic cooling is a method that can allow transferring molecules into a single partial-wave regime. This process is based on cooling species by immersion in a gas of coolant atoms. The method relies on elastic collisions to transfer momentum between the hot molecules and the coolant atoms. Inelastic collisions are detrimental to the cooling process as they release the internal energy of trapped molecules, leading to undesirable heating and trap loss. In addition, the inelastic collisions might also lead to final states that are no longer trappable. By providing numerical results, we show that the ultracold SrF molecule (recently laser-cooled into the microkelvin regime) is a promising candidate to be sympathetically cooled by collisions with Rb atom in the presence of a magnetic field. A key step into this direction has been an evaluation of the ratio between elastic and inelastic collisions for the spin-polarized SrF and Rb complex. In particular, the state-of-the-art ab initio calculations have been employed to obtain molecular properties and the potential energy surface in the lowest triplet state. Next, the scattering parameters have been obtained using the converged close-coupling calculations based on the total angular momentum representation in the body-fixed coordinate frame.

Q 61.3 Fri 14:30 e415

Spectroscopic studies on the lowest triplet states of AlF — •Nicole Walter[1], Silvio Marx[1], Maximilian Doppelbauer[1], Jesús Pérez-Ríos[1], Boris Sartakov[2], Sebastian Kray[1], Simon Hofsäss[1], Christian Schewe[1], Stefan Truppe[1], and Gerard Meijer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin — [2]General Physics Institute, Russian Academy of Sciences, Vavilovstreet 38, 119991 Moscow, Russia

Aluminum monofluoride (AlF) is an excellent candidate for laser cooling. The spin-forbidden $a^3\Pi$ - $X^1\Sigma^+$ transition can be used to achieve final temperatures in the low μK range.

The metastable a-state allows high spectral resolution due to its long lifetime ($\sim$ 1 ms). Using a jet-cooled, pulsed molecular beam, rf-transitions between opposite parity Λ-doublet levels are measured. We observe Rabi-lineshapes narrower than 1.5 kHz. By increasing the interaction time of the molecules with the rf-field, lines narrower than the natural linewidth can be obtained.

The parity selective detection of AlF in the a-state is done by resonant ionization via the $b^3\Sigma^+$ or $c^3\Sigma^+$-state. For this, we measure rotational-resolved spectra of all the involved states. Furthermore, the predicted lifetimes of the a, b and c-states are experimentally verified.

Q 61.4 Fri 14:45 e415

Spectroscopic studies of spin-forbidden transitions in aluminum monofluoride — •Maximilian Doppelbauer[1], Silvio Marx[1], Simon Hofsäss[1], Nicole Walter[1], Sebastian Kray[1], Christian Schewe[1], Boris Sartakov[2], Jesús Pérez-Ríos[1], Stefan Truppe[1], and Gerard Meijer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]General Physics Institute, Russian Academy of Sciences, Vavilovstreet 38, 119991 Moscow, Russia

Aluminum monofluoride (AlF) is an excellent candidate for laser cooling on any Q-line of the $A^1\Pi$ - $X^1\Sigma^+$ transition and trapping at high densities[1]. Narrow-line laser cooling on the spin-forbidden $a^3\Pi$ - $X^1\Sigma^+$ transition can be used to reduce the temperature further. The $A^1\Pi \rightarrow a^3\Pi$ decay channel can lead to losses from the optical cycle.
Prior to cooling and trapping experiments, it is necessary to measure the detailed energy level structure in the $X^1\Sigma^+$ electronic ground state, in the $A^1\Pi$ state and in the metastable $a^3\Pi$ state as well as the strength of the transitions between these states.
Here, we report on our investigations of the $a^3\Pi$ - $X^1\Sigma^+$ and $A^1\Pi$ - $a^3\Pi$ transitions of aluminum monofluoride.

[1] Truppe et al., Phys. Rev. A 100, 052513 (2019)

Q 61.5 Fri 15:00 e415

P,T-Violting effects in polyatomic molecules – An electronic structure perspective — •Konstantin Gaul and Robert Berger — Fachbereich Chemie, Philipps-Universität Marburg,Hans-Meerwein-Straße 4, 35032 Marburg

"New physics" beyond the standard model, such as supersymmetry, can imply larger simultaneous violations of parity (P) and time-reversal (T) symmetry and therewith predict more pronounced non-vanishing permanent electric dipole moments (EDMs) than the standard model. In polar molecules electronic structure enhances such P,T-odd effects and thus low-energy high-precision experiments on these molecules can give access to the TeV energy-regime[1]. With the proposal of laser-cooling of polyatomic molecules[2] and its experimental evidence[3], new possibilities to improve molecular searches for P,T-violation employing the advantages of polyatomic molecules were demonstrated[4].

In this contribution the electronic structure enhancement of P,T-odd effects in laser-coolable polyatomic molecules including vibrational effects will be discussed. Scaling behavior with respect to nuclear charge numbers and disentanglement of different sources of P,T-violation are highlighted.

[1] D. DeMille, Physics Today 68, 34 (2015).
[2] T. A. Isaev, R. Berger, Phys. Rev. Lett. 116, 063006 (2016).
[3] I. Kozyryev et. al., Phys. Rev. Lett. 118, 173201 (2017).
[4] I. Kozyryev, N. R. Hutzler, Phys. Rev. Lett. 119, 133002 (2017).
[5] K. Gaul, R. Berger, Phys. Rev. A accepted for publication, (2019), arXiv:1811.05749 [physics.chem-ph].

Q 62: Control (joint session MO/Q)

Time: Friday 14:00–16:00 Location: f102

Q 62.1 Fri 14:00 f102

Control of molecular alignment using tailored picosecond laser pulses — •Stefanie Kerbstadt[1], Emil Zak[1], Andrey Yachmenev[1], Sebastian Trippel[1,2], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Center for Ultrafast Imaging, Universität Hamburg — [3]Department of Physics, Universität Hamburg

The control of molecular axes is essential for fundamental studies of molecular structure and of chemical reactions. Strong non-resonant laser fields have been established as powerful tool to control and to fix molecular axes in space, providing access to molecular-frame spectroscopy and imaging experiments. Here, we present experimental as well as theoretical results on the refined control of field-free molecular alignment and angular-momentum alignment by employing shaped picosecond pulses to a ground state-selected cold molecular beam of carbonylsulfid (OCS).

Q 62.2 Fri 14:15 f102

A comparative study on ionization-induced dissociation of hydrogen, irradiated by 800 nm and 400 nm laser fields — •René Wagner[1], Saba Arife Bozpolat[2], Patrik Grychtol[1], Ilhan Yavuz[2], and Michael Meyer[1] — [1]Small Quantum Systems Group, European XFEL GmbH, 22869 Schenefeld, Germany — [2]Physics Department, Marmara University, 34722 Ziverbey, Istanbul, Turkey

We present a two color investigation of the hydrogen molecule to benchmark our tabletop experiment dedicated to ultrafast investigations of electronic correlations in atoms and molecules from the near infrared (NIR) to the extreme ultraviolet (EUV) range. Our setup focuses on the study of dissociating molecules by different pump-probe techniques aiming to obtain invaluable and novel insights into atomic and molecular dynamics. For this purpose, we have built a femtosecond laser driven EUV source based on high harmonic generation (HHG) combining it with a pulsed molecular jet, a delay-line based velocity map imaging (VMI) detector and a time-of-flight (TOF) spectrometer. We are going to show first experimental as well as theoretical results quantifying the performance of our apparatus having captured and analysed the angular ion momentum distribution of the photo-induced dissociation process of hydrogen, irradiated by ultrafast 800 nm and 400 nm laser fields.

[1] Ibrahim *et al.*, J. Phys B: At. Mol. Opt. Phys. **51** (2018) 042002.

Q 62.3 Fri 14:30 f102

Electron-vibrational coupling dynamics in SF_6 — •Patrick Rupprecht[1], Lennart Aufleger[1], Alexander Magunia[1], Simon Heinze[2], Thomas Ding[1], Marc Rebholz[1], Stefano Amberg[1], Nikola Mollov[1], Felix Henrich[1], Maurits Haverkort[2], Christian Ott[1], and Thomas Pfeifer[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Universität Heidelberg, Institut für Theoretische Physik

Visible and infrared vibrational spectroscopy, probing non-localized electronic molecular states, is commonly used in chemistry and biology. In combination with core-level spectroscopy, studies of coherently coupled electronic and vibrational dynamics with site and element specificity are possible. We report on the investigation of sulfur hexafluoride (SF_6) using attosecond transient absorption spectroscopy driven by mJ-level, few-cycle 15 fs FWHM pulses centered at 1550 nm in the short-wave infrared (SWIR) spectral region. The excited $6a_{1g}$, $2t_{2g}$ and $4e_g$ molecular states related to the sulfur $L_{2,3}$ absorption edge were probed. First, altering the absorption spectrum in the 160 eV to 200 eV soft X-ray (SXR) region under the presence of a strong SWIR field was demonstrated. Furthermore, varying the delay between the SXR and SWIR pulses resulted in an oscillatory behavior of the resonance lines' intensities, with a leading SWIR pulse. The extracted oscillation period of (773 ± 16) cm^{-1} matches the Raman-active symmetric breathing mode $\nu_1 = 775$ cm^{-1}. This result implies sensitivity to nonresonant impulsive stimulated Raman scattering via probing electronic transitions to states localized near the sulfur atom.

Q 62.4 Fri 14:45 f102

Laser-induced alignment of nanoparticels — •Hakan Akarsu[1,2], Muhamed Amin[1], Lena Worbs[1,2], Jannik Lübke[1,2,3], Armando Estillore[1], Amit K. Samanta[1], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen Synchrotron DESY, Hamburg — [2]Fachbereich Physik, Universität Hamburg — [3]Center for Ultrafast Imaging, Universität Hamburg

Single-particle imaging (SPI) experiments at free-electron lasers (FELs) promise high-resolution-imaging of the structure and dynamics of nanoparticles. By guiding sample molecules in the gas phase into the x-ray focus of an FEL, diffraction patterns of individual particles can be collected. Sufficient amounts of patterns of identical nanoparticles are needed to overcome the inherently small signal-to-noise ratio and reconstruct the underlying 3D structure [1]. Laser-induced alignment of nanoparticles has potential to improve the achievable resolution and to push it toward the atomic scale [2,3].

Here, we present simulation results on laser-induced alignment of gold nanorods by integrating the Euler equation of rotational motion. We have also tested different laser pulse profiles for improvement of the alignment. In addition, we will present first experimental investigations of the laser-induced alignment of gold nanorods.

[1] M. M. Seibert, et al., Nature 470, 78 (2011)
[2] J. C. H. Spence, et al., Phys. Rev. Lett. 92, 198102 (2004)
[3] J. Küpper, et al., Phys. Rev. Lett. 112, 083002 (2014)

Q 62.5 Fri 15:00 f102

Rotational spectroscopy of molecular superrotors: probing high rotational states of O_2 via REMPI technique combined with an optical centrifuge. — •Audrey Scognamiglio[1], Jordan Fordyce[2], Ian MacPhail-Bartley[2], Katrin Dulitz[1], Frank Stienkemeier[1], and Valery Milner[2] — [1]Institut of Physics, University of Freiburg, Germany — [2]Department of Physics and Astronomy, University of British Columbia, Canada

To access highly excited rotational states (e.g. N=100 in O_2), the use of an optical centrifuge has been demonstrated to be a powerful and unique experimental tool.

To start from a well-defined initial ro-vibrational state, oxygen molecules are cooled to 10K by means of supersonic expansion. Due to the relatively low density, spectroscopic techniques combining high frequency resolution and high sensitivity are required. For this purpose, resonance enhanced multiphoton ionization of oxygen is employed in a "2+1" scheme with a two-photons transition from the ground state $X^3\Sigma_g^-$ $(\nu = 0)$ to the excited state $C^3\Pi_g$ $(\nu = 2)$ from which another photon ionizes the molecule.

In this contribution, experimental results of REMPI spectroscopy of oxygen superrotors, as well as their numerical analysis, will be presented.

Q 62.6 Fri 15:15 f102

Setting the basis for a good Carrier Envelope Phase control — •Franziska Schüppel, Thomas Schnappinger, and Regina de Vivie-Riedle — Department Chemie, Ludwig-Maximilians-Universität München

Controlling the process of photo reactions is a major goal in chemistry. For synthetic application, for example, it is significant to have the desired product in the best possible yield. To achieve this, one approach is to apply a few-cycle IR laser pulse to a system in the vicinity of a conical intersection (CoIn).[1] This influences the system in a way to build a superposition between the states of interest. By changing the CEP (Carrier Envelope Phase) of the laser pulse, the superposition can be controlled to lead to the preferred transfer through the CoIn and by that to the preferred product.

In this theoretical work, we want to investigate the effectiveness of a CEP control on the basis of a dissociative model system. For that, we use quantum dynamic simulations with two coupled states in the adiabatic representation. We want to describe the interaction of the laser pulse, the transition dipole moment and the non-adiabatic coupling on the CEP control and find the basis needed for an effective control of a system. By changing the shape of the CoIn of the model system, we want to test the influence of a different topography on the CEP control.

[1] P. von den Hoff *et al.*, *IEEE J SEL TOP QUANT*, **18** (2012), 119-129.

Q 62.7 Fri 15:30 f102

Controlling the nuclear- and electron-dynamics at a conical intersection — •Thomas Schnappinger, Franziska Schüppel, and Regina de Vivie-Riedle — Department of Chemistry, LMU Munich, Germany

The combination of ultra-fast optical techniques with quantum dynamics simulations give extensive insights into the nuclear and electronic dynamics of molecules and give rise to the possibility of modifying or even controlling the dynamics.

In this theoretical work we aim to control the coupled nuclear- and electron-dynamics in the vicinity of a conical intersection (CoIn). The control scheme relies on the carrier envelope phase (CEP) of a few-cycle IR pulse. The laser interaction creates an electronic superposition of the involved states before the wavepacket reaches the CoIn and influences the population transfer through the CoIn. To simulate the coupled nuclear- and electron-motion of this process we are using the NEMol (coupled nuclear- and electron-dynamics in molecules) ansatz developed in our group. In this purely quantum mechanical ansatz the quantum-dynamical description of the nuclear motion is combined with the calculation of the electron-dynamics in the eigenfunction basis.

We want to show two examples the molecule NO2 and the nucleobase uracil. Both systems show relaxation dynamics back in the ground state via a CoIn after photoexcitation. But the circumstances, e.g. the transitional dipole moment and the localization of the wavepacket, differ significantly in both systems. These facts should be reflected in the controllability of the relaxation.

Q 62.8 Fri 15:45 f102

Laser induced electron diffraction in the molecular frame — •Joss Wiese[1,2], Jolijn Onvlee[1,3], Andrea Trabattoni[1,3], Evangelos Karamatskos[1,4], Sebastian Trippel[1,3], and Jochen Küpper[1,2,3,4] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Chemistry, Universität Hamburg — [3]The Hamburg Center for Ultrafast Imaging, Universität Hamburg — [4]Department of Physics, Universität Hamburg

Laser-induced electron diffraction (LIED) has the potential to provide time-dependent images of molecules at sub-femtosecond and few-picometer resolution and is therefore ideally suited to record quantum molecular movies. Here we present our work on LIED and strong field ionization off strongly aligned molecular samples. Our samples include simple linear molecules like OCS as well as prototypical biomolecules such as indole and its microsolvated clusters. Effects of the overall strong-field recollision dynamics on the orientation of the molecules will be presented and compared with time dependent density-functional theory (TDDFT) simulations as well as with novel highly efficient semiclassical simulations based on the adiabatic tunneling theory. Our findings have strong impact on the interpretation of self-diffraction experiments, where the photoelectron momentum distribution is used to retrieve molecular structures.