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

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Overview of Invited Talks and Sessions

(Lecture hall H1, H2, H5; Poster P)

Invited Talks

Q 1.1	Mon	11:45–12:15	H1	**Towards phonon engineering at the nanoscale: material design and innovative experimental techniques** — •Ilaria Zardo
Q 1.2	Mon	12:15–12:45	H1	**Hilbert space structure of eigenstates in many-body quantum systems** — •Alberto Rodríguez
Q 9.1	Wed	10:45–11:15	H2	**Critical dynamics and prethermalization in lattice gauge theories** — •Jad Halimeh, Philipp Hauke
Q 9.2	Wed	11:15–11:45	H2	**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 9.3	Wed	11:45–12:15	H2	**New physical concepts: Fermionic Exchange Force and Bose-Einstein Force** — •Christian Schilling

Invited talks of the joint symposium Trends in atom interferometry (SYAI)

See SYAI for the full program of the symposium.

SYAI 1.1	Mon	14:00–14:30	Audimax	**Atom interferometry and its applications for gravity sensing** — •Franck Pereira dos Santos, Luc Absil, Yann Balland, Sébastien Merlet, Maxime Pesche, Raphaël Piccon, Sumit Sarkar
SYAI 1.2	Mon	14:30–15:00	Audimax	**Atom interferometry for advanced geodesy and gravitational wave observation** — •Philippe Bouyer
SYAI 1.3	Mon	15:00–15:30	Audimax	**3D printing methods for portable quantum technologies** — •Lucia Hackermüller
SYAI 1.4	Mon	15:30–16:00	Audimax	**Fundamental physics with atom interferometry** — •PAUL HAMILTON

Invited talks of the joint symposium SAMOP Dissertation Prize 2021 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	10:45–11:15	Audimax	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYAD 1.2	Tue	11:15–11:45	Audimax	**About the interference of many particles** — •Christoph Dittel
SYAD 1.3	Tue	11:45–12:15	Audimax	**Supersolid Arrays of Dipolar Quantum Droplets** — •Fabian Böttcher
SYAD 1.4	Tue	12:15–12:45	Audimax	**Quantum Logic Spectroscopy of Highly Charged Ions** — •Peter Micke

Invited talks of the joint symposium Chirality meets ultrafast (SYCU)

See SYCU for the full program of the symposium.

SYCU 1.1	Tue	14:00–14:30	Audimax	**Overview of the temporal dependencies of Photoelectron Circular Dichroism** — •Valerie Blanchet
SYCU 1.2	Tue	14:30–14:45	Audimax	**Ultrafast, all-optical, and highly enantio-sensitive imaging of molecular chirality** — •David Ayuso
SYCU 1.3	Tue	14:45–15:00	Audimax	**Hyperfine interactions in rotational chiral states** — •Andrey Yachmenev
SYCU 1.4	Tue	15:00–15:30	Audimax	**Chiral molecules in an optical centrifuge** — •Valery Milner, Alexander Milner, Ilia Tutunnikov, Ilya Averbukh
SYCU 1.5	Tue	15:30–16:00	Audimax	**Enantiomer-selective controllability of asymmetric top molecules** — •Monika Leibscher

Invited talks of the joint symposium Awards Symposium (SYAW)

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	13:30–14:15	Audimax	**Frequency comb spectroscopy and interferometry** — •Nathalie Picqué
SYAW 1.2	Wed	14:15–15:00	Audimax	**Capitalizing on Schrödinger** — •Wolfgang P. Schleich
SYAW 1.3	Wed	15:00–15:45	Audimax	**Quantum information processing with macroscopic objects** — •Eugene Polzik

Invited talks of the joint symposium Hot topics in cold molecules: From laser cooling to quantum resonances (SYCM)

See SYCM for the full program of the symposium.

SYCM 1.1	Fri	14:00–14:30	Audimax	**Collisions between laser-cooled molecules and atoms** — •Michael Tarbutt
SYCM 1.2	Fri	14:30–15:00	Audimax	**Trapped Laser-cooled Molecules for Quantum Simulation, Particle Physics, and Collisions** — •John Doyle
SYCM 1.3	Fri	15:00–15:30	Audimax	**Quantum-non-demolition state detection and spectroscopy of single cold molecular ions in traps** — •Stefan Willitsch
SYCM 1.4	Fri	15:30–16:00	Audimax	**Quantum state tomography of Feshbach resonances in molecular ion collisions via electron-ion coincidence spectroscopy** — •Edvardas Narevicius

Sessions

Q 1.1–1.2	Mon	11:45–12:45	H1	**Quantum Nano-Optics and Quantum Effects**
Q 2.1–2.13	Mon	16:30–18:30	P	**Nano-Optics and Optomechanics**
Q 3.1–3.10	Mon	16:30–18:30	P	**Photonics and Laser Development**
Q 4.1–4.21	Mon	16:30–18:30	P	**Precision spectroscopy of atoms and ions (joint session A/Q)**
Q 5.1–5.3	Tue	14:00–15:30	H1	**Ultracold atoms, ions, and BEC I (joint session A/Q)**
Q 6.1–6.17	Tue	16:30–18:30	P	**Quantum Gases and Matter Waves (joint session Q/A)**
Q 7.1–7.14	Tue	16:30–18:30	P	**Precision Measurements**
Q 8.1–8.5	Tue	16:30–18:30	P	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
Q 9.1–9.3	Wed	10:45–12:15	H2	**Quantum Gases**
Q 10.1–10.4	Wed	14:00–16:00	H1	**Precision spectroscopy of atoms and ions / Highly charge ions (joint session A/Q)**
Q 11.1–11.27	Wed	16:30–18:30	P	**Quantum Information (joint session QI/Q)**
Q 12.1–12.6	Wed	16:30–18:30	P	**Quantum Technology**
Q 13.1–13.27	Wed	16:30–18:30	P	**Ultra-cold atoms, ions, and BEC (joint session A/Q)**
Q 14.1–14.3	Thu	10:45–12:15	H1	**Ultracold atoms, ions, and BEC II / Ultracold plasmas and Rydberg systems (joint session A/Q)**
Q 15	Thu	13:00–14:00	MVQ	**General Assembly of the Quantum Optics and Photonics Division**
Q 16.1–16.12	Thu	16:30–18:30	P	**Quantum Optics**
Q 17.1–17.14	Thu	16:30–18:30	P	**Quantum Effects**

General Assembly of the Quantum Optics and Photonics Division

Donnerstag 13:00–14:00 MVQ

Q 1: Quantum Nano-Optics and Quantum Effects

Time: Monday 11:45–12:45 Location: H1

Invited Talk Q 1.1 Mon 11:45 H1

Towards phonon engineering at the nanoscale: material design and innovative experimental techniques — •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. However, engineering and probing phonons and phonon transport at the nanoscale is a non-trivial problem.

In this talk, we discuss how phononic properties can be engineered in nanowires and the challenges and progresses in the measurement of phonons and of the thermal conductivity of nanostructures and low dimensional systems.

Invited Talk Q 1.2 Mon 12:15 H1

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

In this talk, we will explore the characterization of the eigenstate structure in Hilbert space for sytems of 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], and how it is useful to characterize the emergence of chaos in systems of interacting bosons [4].

[1] J. Lindinger, A. Buchleitner, A. Rodríguez, PRL 122, 106603 (2019).
[2] D. J. Luitz, F. Alet, N. Lafl orencie, PRL 112, 057203 (2014).
[3] N. Macé, F. Alet, N. Lafl orencie, PRL 123, 180601 (2019).
[4] L. Pausch et al., PRL 126, 150601 (2021).

Q 2: Nano-Optics and Optomechanics

Time: Monday 16:30–18:30 Location: P

Q 2.1 Mon 16:30 P

Fiber-pigtailing quantum-dot cavity-enhanced light emitting diodes — Lucas Rickert[1], •Frederik Schröder[1], Timm Gao[1], Christian Schneider[2,3], Sven Höfling[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Technische Physik, Physikalisches Institut, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Würzburg, Germany — [3]Institut für Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany

Semiconductor quantum dots embedded in engineered microcavities are considered key building blocks for photonic quantum technologies [1]. The direct fiber-coupling of respective devices would thereby offer many advantages for practical applications [2]. Here, we present a method for the direct and permanent coupling of electrically operated quantum-dot micropillar-cavities to single-mode fibers [3]. The fiber-coupling technique is based on a robust four-step process fully carried out at room temperature, which allows for the deterministic coupling of a selected target device. Using the cavity mode electroluminescence as feedback parameter, precise fiber-to-pillar alignment is maintained during the whole process. Permanent coupling is achieved in the last process step using UV curing of optical adhesive. Our results are an important step towards the realization of plug-and-play benchtop electrically-driven single-photon sources.

[1] T. Heindel et al., Appl. Phys. Lett. 96, 11107 (2010)
[2] T. Kupko et al., arXiv.2105.03473 (2021)
[3] L. Rickert et al., arXiv.2102.12836 (2021)

Q 2.2 Mon 16:30 P

Tailoring the thermal noise of membrane-based interferometric measurement schemes — •Johannes Dickmann[1,2], Mariia Matiushechkina[2,3], Jan Meyer[1,2], Anastasiia Sorokina[1,2], Tim Käseberg[4], Stefanie Kroker[1,2], and Michèle Heurs[2,3] — [1]Laboratory for Emerging Nanometrology (LENA), Technical University of Braunschweig, Langer Kamp 6a/b, 38106 Braunschweig — [2]Cluster of Excellence QuantumFrontiers — [3]Max Planck Institute for Gravitational Physics, Leibniz University Hannover, Callinstraße 38, 30167 Hannover — [4]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

The interaction of mechanical systems like membranes with the optical light field inside interferometers established access to manifold measurement schemes. The application of these measurement schemes spans the optical cooling of membranes, the investigation and manipulation of macroscopic quantum states, the detection and analysis of viruses and bacteria as well as the generation of non-classical states of light for quantum computing and gravitational wave detection. We present the analysis of thermal noise sources, which severely influence the performance of membrane-based interferometric measurement schemes. In particular, the influence of structural parameters such as geometry, temperature and loss mechanisms are studied to provide guidelines for future experimental set-ups.

Q 2.3 Mon 16:30 P

Measurement of the photoelastic constant at cryogenic temperatures for the calculation of the photoelastic noise of the Einstein Telescope — •Jan Meyer[1,2], Johannes Dickmann[1,2], Mika Gaedtke[1,2], and Stefanie Kroker[1,2] — [1]Laboratory for Emerging Nanometrology (LENA),Langer Kamp 6a/b, 38106 Braunschweig, Germany — [2]Cluster of Excellence QuantumFrontiers

Currently most precise measurement instruments are gravitational wave detectors with a relative precision of less than 10^{-23}. This accuracy is limited by various noise sources. Most of the critical noise sources are driven by thermal fluctuation in the optical components of the detector, e.g. input mirrors of the cavities in the interferometer arms or the beamsplitter. To further enhance the sensitivity and, thus, the detection range, all potentially critical noise sources must be quantified and, if possible, mitigated. In this poster we present for the first time a noise source based on the photoelastic effect in solids. The photoelastic effect describes the change of the refractive index based on the local deformation of a material. The thermal fluctuations inside the optical parts lead to local deformations and, hence, to the local change of the refractive index. We present first calculations of the photoelastic noise for the Einstein Telescopes beamsplitter at a temperature of 300 K and the input mirrors of the cavities in the interferometer arms at 10 K. Due to the insufficient literature values of the photoelastic constant at cryogenic temperature, we developed a measurement setup to close this knowledge gap.

Q 2.4 Mon 16:30 P

A cavity optomechanical locking scheme based on the optical spring effect — •Felix Klein[1], Jakob Butlewski[1], Alexander Schwarz[2], Roland Wiesendanger[1,2], Klaus Sengstock[1,3], and Christoph Becker[1,3] — [1]ZOQ (Zentrum für Optische Quantentechnologien), Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]INF (Institut für Nanostruktur- und Festkörperphysik), Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany — [3]ILP (Institut für Laserphysik), Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We present a new method for stabilizing the length of a cavity optomechanical device using the optical spring effect, i.e. the detuning dependent frequency shift of a nanomechanical device caused by optomechanical coupling to the intra-cavity field. The error signal is based on this frequency shift, which is derived from the continuous position measurement of the nanomechanical device. Our locking scheme does not require any additional laser- or cavity modulation and its technical implementation is straightforward. The optical spring lock specifically suits systems with large linewidth such as e.g. microcavities and can be considered as an alternative when other locking schemes appear unfavorable. We demonstrate the implementation of this lock in a fiber-based Fabry-Perot membrane-in-the-middle optomechanical device and characterize its performance in terms of bandwidth and gain profile.

Q 2.5 Mon 16:30 P

Polymer drum resonators in fiber Fabry-Perot cavities — Lukas Tenbrake[1], Alexander Fassbender[2], Sebastian Hofferberth[1], Stefan Linden[2], and •Hannes Pfeifer[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Physics, University of Bonn, Germany

Cavity optomechanical experiments have been demonstrated on a wide range of experimental platforms during the past years. Record optomechanical coupling strengths were reached in micro- and nanophotonic realizations, which require elaborate techniques for interfacing and are limited in scaling towards multimode systems, tunability and flexibility. Here, we demonstrate a cavity optomechanical experiment that uses 3D laser written polymer structures inside fiber Fabry-Perot cavities. First experiments show vacuum coupling strengths of $\gtrsim 10\,\text{kHz}$ at mechanical mode frequencies of $\gtrsim 1\,\text{MHz}$. The extreme flexibility of the laser writing process allows for a direct integration of the mechanical resonator into the microscopic cavity. The ease of interfacing the system through the direct fiber coupling, its scaling capabilities to larger systems with coupled resonators, and the possible integration of electrodes makes it a promising platform for upcoming challenges in cavity optomechanics. Fiber-tip integrated accelerometers, directly fiber coupled systems for microwave to optics conversion or large systems of coupled mechanical resonators are in reach.

Q 2.6 Mon 16:30 P

Nanofiber-induced losses inside an optical cavity — •Sebastian Slama, Bernd Welker, and Thorsten Österle — Center for Quantum Science and Physikalisches Institut, Universität Tübingen, Germany

Optical cavities are well-known to enhance light-matter interactions, and are an established tool in the context of cold atoms. In contrast, putting single solid emitters into cavity modes remains a challenge, mainly due to the fact that the typically plane substrates, where the emitters are embedded, lead to a substantial optical loss in the cavity. We follow the idea to use nanofibers with sub-wavelength diameter as possible substrates with low loss. We have experimentally measured the nanofiber-induced loss inside an optical cavity with a finesse of F=1250 as function of nanofiber position for various nanofiber diameters. Only little reduction of the finesse is observed for a fiber diameter of 150 nm. The observations are consistent with the optical loss induced by Mie scattering theory.

Q 2.7 Mon 16:30 P

High-resolution spectroscopy and nanoscale mode mapping of photonic microresonators in a transmission electron microscope — Jan-Wilke Henke[1,2], Arslan Sajid Raja[3], Armin Feist[1,2], Guanhao Huang[3], Germaine Arend[1,2], Yujia Yang[3], •F. Jasmin Kappert[1,2], Rui Ning Wang[3], Marcel Möller[1,2], Jiahe Pan[3], Junqiu Liu[3], Ofer Kfir[1,2,4], Tobias J. Kippenberg[3], and Claus Ropers[1,2] — [1]Georg-August-Universität, Göttingen, Germany — [2]Max Planck Institute for Biophysical Chemistry, Göttingen, Germany — [3]Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland — [4]School of Electrical Engineering, Tel-Aviv University, Tel-Aviv, Israel

Ultrafast electron microscopes are a powerful platform for investigating nano photonic devices, as they provide direct access to optical near-fields in photon-induced near-field electron microscopy (PINEM).

In this work, we demonstrate for the first time the spatial and spectral characterization of a single optical mode in a photonic-chip-based high-Q microresonator by electron microscopy. We map the evanescent cavity field with nanometer spatial and μeV energy resolution by laser-frequency-tuned electron energy-gain spectroscopy [1].

Future studies will explore the application of various nonlinear effects in integrated photonics for temporal and spectral electron-beam control, including dissipative Kerr solitons.

[1] J.-W. Henke, A. S. Raja, et al., preprint, arXiv:2105.03729 (2021)

Q 2.8 Mon 16:30 P

Precise Approaches for Determining Transition Rates and Quantum Efficiency of Single Color Centers — •Di Liu[1,2], Naoya Morioka[3], Öney Soykal[4], Izel Gediz[1,2], Charles Babin[1,2], Rainer Stöhr[1,2], Takeshi Ohshima[5], Nguyen tien Son[6], Jawad Ul-Hassan[6], Florian Kaiser[1,2], and Jörg Wrachtrup[1,2] — [1]3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany — [2]Institute for Quantum Science and Technology (IQST), Germany — [3]Institute for Chemical Research, Kyoto University, Uji, Japan — [4]Booz Allen Hamilton, McLean, VA, USA — [5]National Institutes for Quantum and Radiological Science and Technology, Takasaki, Japan — [6]Department of Physics, Chemistry and Biology, Linköping, Sweden

Optically-active spins in solids are appealing candidates for quantum technological applications due to the unique interplay between their spins and photons. The performance of those spin-based technologies is further boosted with highly-efficient spin-photon interfaces, such as a nanophotonic resonantor. The design of such nanostructures requires comprehensive understanding of the system's spin-optical dynamics. To overcome this, we developed a full set of measurements combining sublifetime short resonant and off-resonant pulses to infer the transition rates of a single color center i.e. V1 center in silicon carbide, with high precision. With those measured rates, we also estimated the quantum efficiency of the system. Our method paves way for a better understanding of the intrinsic properties of color centers, which in turn guides the design of nanophotonic resonators.

Q 2.9 Mon 16:30 P

Quantitative Waveform Sampling on Atomic Scales — •Lukas Kastner[1], Dominik Peller[1], Carmen Roelcke[1], Thomas Buchner[1], Alexander Neef[1], Johannes Hayes[1], Franco Bonafé[2], Dominik Sidler[2], Angel Rubio[2,3,4], Rupert Huber[1], and Jascha Repp[1] — [1]University of Regensburg, Germany — [2]MPSD, MPG, Hamburg, Germany — [3]CCQ, Flatiron Institute, New York, USA — [4]UPV/EHU, San Sebastían, Spain

Using a single molecule as a local field sensor, we precisely sample the absolute field strength and temporal evolution of tip-confined nearfield transients in a lightware-driven scanning tunnelling microscope. To develop a comprehensive understanding of the extracted atomic scale nearfield, we simulated the far-to-near-field transfer with classical electrodynamics and include time-dependent density functional theory to validate our calibration and conclusions.

Q 2.10 Mon 16:30 P

Investigating and Improving the Quantum Efficiency of Defect Centers in hBN — •Pablo Tieben[1,2], Bhagyesh Shiyani[2], Nora Bahrami[2], Hiren Dobarya[2], and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]Institute for Solid State Physics, Leibniz University Hannover, Appelstr. 2, 30167 Hannover

Single photon emitters play a central role in the rapidly developing field of quantum technologies. Therefor new sources of single photons are highly sought after and understanding their properties is essential for their application in quantum technologies. Defect centers in hexagonal boron nitride (hBN) have become prominent candidates as single photon sources due to some of their highly favorable properties, like bright single photon emission, narrow line width, and high photo stability at room-temperature. Recently a spectral dependency on the excitation wavelength of the fluorescence of these emitters has been shown. In general, both the intensity and purity of the quantum emission, as well as the emission spectrum, vary with the excitation wavelength. By tuning the excitation over a broad range inside the visible spectrum and performing measurements regarding the quantum nature as well as the spectral decomposition of the emission light, we gain further insight to the characteristic properties and energy level schemes of these defect centers. In particular we find a strong dependency of the saturation behavior of individual emitters on the excitation wavelength and thus show, that the single photon emission of optically active defects in hBN has a tunable quantum efficiency.

Q 2.11 Mon 16:30 P

Shallow implantation of color centers in silicon carbide with high-coherence spin-optical properties — •Timo Steidl[1], Tobias Linkewitz[1], Raphael Wörnle[1], Charles Babin[1], Rainer Stöhr[1], Di Liu[1], Erik Hesselmeier[1], Naoya Morioka[1], Vadim Vorobyov[1], Andrej Denisenko[1], Mario Hentschel[1], Christian Gobert[2], Patrick Berwian[2], Georgy Astakhov[3], Wolfgang Knolle[4], Sridhar Majety[5], Pranta Saha[5], Marina Radulaski[5], Nguyen Tien Son[6], Jawad Ul-Hassan[6], Florian Kaiser[1], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, Germany — [2]Fraunhofer IISB, Erlangen, Germany — [3]HZDR, Dresden, Germany — [4]IOM, Leipzig, Germany — [5]University of California, Davis, USA — [6]Linköping University, Sweden

Next-generation solid-state quantum information devices require efficient photonic interfaces, e.g., as provided by cavity QED systems. This requires precise positioning of optically active color centers in the centre of such cavities. Here, we report the creation of shallow silicon vacancy centers in silicon carbide with high spatial resolution using implantation of protons, He ions and Si ions. We observe remarkably robust spin-optical properties, e.g., nearly lifetime limited absorption lines and the highest reported Hahn echo spin-coherence times of the system. We attribute these findings to the much lower ion energy used in our experiments (few keV), which minimizes collateral crystal damage. Our findings provide a significant step forward for the SiC platform.

Q 2.12 Mon 16:30 P

Single-Molecule 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, Erlangen, Germany — [2]Friedrich Alexander University, Erlangen, Germany

One-dimensional subwavelength waveguides (nanoguides) are very promising candidates for exploring the rich physics of quantum many body systems. However, the efficiency of coupling between an individual emitter, e.g., an organic dye molecule and a realistic nanoguide is limited by geometric and material constrains and a rich internal level structure of the emitters. To address these issues, we employed TiO_2 nanoguide racetrack resonators and demonstrated a sevenfold Purcell enhancement of the molecule's zero-phonon line emission into the nanoguide mode [1]. Additionally, we explored the use of gallium phosphide (GaP) as a high refractive index nanoguide material. Here, we could observe up to 15% extinction for linear nanoguides, twice higher than for TiO_2 [2]. We also show how studies on the spatio-temporal behavior of several molecules reveal nanoscopic charge fluctuations in GaP. Finally, we discuss our plans for improving the quality factor of our microresonators and for implementing individual control on the molecule frequencies to achieve long-distance photonic coupling of several molecules [3].

[1] D. Rattenbacher et al., New J. Phys. 21, 062002 (2019)
[2] A. Shkarin et al., Phys. Rev. Lett. 126, 133602 (2021)
[3] H. R. Haakh et al., Phys. Rev. A 94, 053840 (2016)

Q 2.13 Mon 16:30 P

Polarization sensitive correlations of single photon emitters in *h*-BN — •Niko Nikolay[1], Florian Böhm[1], Fridtjof Betz[2], Günter Kewes[1], Noah Mendelson[4], Sven Burger[2,3], Igor Aharonovich[4], and Oliver Benson[1] — [1]Institut für Physik & IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]Zuse Institute Berlin, Takustraße 7, 14195 Berlin, Germany — [3]JCMwave GmbH, Bolivarallee 22, 14050 Berlin, Germany — [4]School of Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, New South Wales 2007, Australia

Optically active color centers in hexagonal boron nitride are promising cadidates as single photon sources. Therefore, they have been extensively studied in recent years [1]. Their atomic origin is still unknown, so the experiments presented in this paper shed light on the underlying level structure. We will show that two spectra differing in their polarization contribute to the fluorescence of the observed single photon emitter. Based on these results, we then present polarization-sensitive photon correlation measurements [2] and compare them to a multilevel rate equation model. As a future perspective, we discuss the potential of this theoretical and experimental framework to further explore the electronic level structure of single photon centers in hexagonal boron nitride.

[1] Hayee, Fariah, et al., Nature materials 19.5 (2020): 534-539.
[2] Sontheimer, Bernd, et al., Physical Review B 96.12 (2017): 121202.

Q 3: Photonics and Laser Development

Time: Monday 16:30–18:30 Location: P

Q 3.1 Mon 16:30 P

Modelling of beam propagation for partially coherent light waves in diffractive systems — •Ulf-Vincent Sponholz and Edeltraud Gehrig — RheinMain University of Applied Science, Germany

In many technical applications diffractive systems are used to guide and shape light waves. Typically, these systems are designed according to properties and parameters of an ideal light beam. For a realistic description it is of interest to explicitly consider the beam properties as well as the spectrum of a given light source. We present a mathematical-physical model for the simulation of beam propagation and superposition of partially coherent waves. In the model, using the Fraunhofer approximation for imaging between optical planes, the propagation of light with variable spectral composition and coherence properties is explicitly considered. The beam passes a diffractive system (e.g. phase grating), realized by a corresponding transmission function in the imaging plane. Based on the model equations a practice-oriented Python program was developed, that allows the simulation and comparative analysis of different diffractive optical elements exposed to various light sources. Variable coherence properties (e.g. laser light or LEDs) are captured via a superposition of individual light components using Fourier transform methods. The program enables the realistic calculation of beam profiles after passing through an optical system as well as the adaptation of an imaging optics to a given light source.

Q 3.2 Mon 16:30 P

Hybrid Microring Resonators: towards Integrated Single Photon Emitters with a Novel Fabrication Approach — •Giulio Terrasanta[1], Timo Sommer[1,3], Manuel Müller[2,1], Matthias Althammer[2,1], and Menno Poot[1,3,4] — [1]Department of Physics, Technical University Munich, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [4]Institute for Advanced Study, Technical University Munich, Garching, Germany

Aluminum nitride (AlN) is an emerging material for integrated quantum photonics, thanks to its excellent linear and nonlinear optical properties. Its second-order nonlinearity allows the realization of single photon emitters, which are a critical component for quantum technologies. Nevertheless, the fabrication of AlN, in particular its etching, can be challenging. Here, we demonstrate the integration of AlN on Silicon Nitride (SiN) photonic circuits with a novel approach that depends only on the SiN reliable fabrication. By sputtering c-axis oriented AlN on top of pre-patterned SiN, we realized hybrid microring resonators. The material properties were characterized using XRD, optical reflectometry, SEM, and AFM. We varied AlN thickness, ring radius, and waveguide width in different chips to benchmark the optical properties, such as the quality factor, propagation losses and group index. The hybrid resonators can have quality factors as high as 500K, thus being a promising platform to amplify the nonlinear optical properties of AlN.

Q 3.3 Mon 16:30 P

Characterising and tracking the three-dimensional motion and rotation of individual nanoparticles using a high-finesse fibre-based microcavity — Larissa Kohler[1], •Shalom Palkhivala[1], Matthias Mader[2], Christian Kern[1], Martin Wegener[1], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Ludwigs-Maximilians-Universität, Munich, Germany

While many current techniques for nanoparticle sensing are based on labelling, we present a fibre-based high-finesse Fabry-Perot microcavity capable of sensing unlabelled nanoparticles. The optical microcavity is integrated with microfluidic channels for the detection of nanoparticles in solution. Silica nanospheres with radii of 25 nm have thus been detected, and their mean refractive index deduced.

Furthermore, the three-dimensional Brownian motion of a single nanoparticle in the cavity is tracked by the simultaneous measurement of the fundamental and two higher-order transverse modes. The particle's position can be derived with spatial and temporal resolutions of 8 nm and 0.3 ms respectively. In addition, the rotation of nanoparticles is measured by the polarisation splitting of the fundamental mode. The rotation of nanospheres with a specified roundness of 0.98 can already be investigated with this method.

Work is being done to increase the detection bandwidth and sensitivity, to eventually allow characterisation of the optical and dynamic behaviour of single biomolecules.

Q 3.4 Mon 16:30 P

Transportable Laser System Employing Fourier Limited Picosecond Pulses for Laser Cooling of Relativistic Ion Beams — •Benedikt Langfeld[1], Daniel Kiefer[1], Sebastian Klammes[1,2], and Thomas Walther[1] — [1]TU Darmstadt — [2]GSI Darmstadt

Laser cooling of relativistic ion beams has been shown to be a sophisticated technology [1]. To prevent intrabeam scattering (IBS) of the ion beam, the use of white-light cooling with broad laser bandwidths has been proposed and demonstrated in non-relativistic ion beam cooling [2]. Laser cooling of relativistic C^{3+} ion beams was demonstrated with the presented pulsed laser system this year at GSI (see poster by S. Klammes et al).

In this work we present the transportable master-oscillator-power-amplifier system supplying laser pulses of 70 to 740 ps length with a scannable centre wavelength of 1029 nm, using a combination of acousto-optic and electro-optic modulators. The system generates Fourier transform limited pulses with a continuously adjustable pulse length and repetition rate of 1 to 10 MHz. With two SHG stages, the desired wavelength of 257.25 nm can be achieved.

[1] S. Schröder et al, Phys. Rev. Lett. 64, 2901-2904, (1990).

[2] S.N.Atutov et al, Phys. Rev. Lett. 80, 2129, (1998).

Q 3.5 Mon 16:30 P

Towards microcombs for high-resolution astronomy — •Ignacio Baldoni[1], Arne Kordts[1], Junqiu Liu[2], Arslan Raja[2], Tobias Kippenberg[2], and Ronald Holzwarth[1] — [1]Menlo Systems GmbH, Munich, Germany — [2]École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

Precise and accurate calibration of astronomical spectrometers is crucial for the detection of extra-solar planets or direct measurements of cosmological expansion. A decade ago, Laser Frequency Combs presented an improved solution for the traditional calibration light sources where its regular spaced frequency grid spectrum is filtered to higher repetition rates, broadened and flattened to equal comb line intensities of the spectrometer. This system referred as astrocomb has still some drawbacks, especially in the mode filtering and spectral broadening schemes. An alternative to overcome those issues relies in the demonstration of frequency-combs through soliton formation on a low-loss microresonator (microcomb) driven only by a single cw laser. This platform provides large mode spacing on a photonic chip making it attractive for astrocombs. Here, a microcomb system is developed to replace the comb source of current astrocombs operating at 1550 nm. The microresonator fabrication via photonic Damascene process allowed high-Q based on ultralow-loss Si_3N_4 waveguides. Single soliton state at 12 GHz line-spacing was accomplished and stabilized for reliable long-term measurements, alongside with a repetition rate locking scheme. Once broadened, this spectrum will enable high-resolution calibration for astronomical spectrographs.

Q 3.6 Mon 16:30 P

A next generation laser driver and temperation controller — •Patrick Baus, Thomas Sattelmaier, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

We present a fully open source hardware solution for the next generation of diode lasers. Our solution provides superior performance in comparison to typical commercial solutions in the field, while being more economical and versatile due to its open source platform. Our laser current driver offers full digital control, sub-ppm drift and the lowest noise in class. Additional features are a high compliance voltage of more than 10 V to drive modern and exotic laser diodes and a modulation bandwidth with linear response of more than 1 MHz.

Our temperature controller features best in class noise of $<5\ \mu K_{RMS}$ and stability of $<100\ \mu K$ (@ 25 °C) over several weeks limited only by ambient humidity. Our system offers two channels with independant control and up to 60 W.

For both devices, we intend to make the hardware and software publicly available under an open source license to allow full customization.

Q 3.7 Mon 16:30 P

PHONQEE: Playful Hands-on-Quantum Early Education — •Slava Tzanova[1], Wolfgang Dür[2], Stefan Heusler[3], and Ulrich Hoff[4] — [1]qutools GmbH, Munich, Germany — [2]University of Innsbruck, Innsbruck, Austria — [3]University of Muenster, Muenster, Germany — [4]Technical University of Denmark, Kongens Lyngby, Dänemark

The PHONQEE project is exploring novel didactical approaches to teaching of quantum physics, spurring curiosity about quantum phenomena and their interpretation and applications, and stimulating scientific creativity and inquisitive learning in high-school education. The ambition is to facilitate deep learning and assist the students' assimilation of new knowledge about quantum physics by creating a cheerful learning environment and making the abstract concrete. The project has an undivided focus on 'hands-on' as physical and tactile activity has unique learning and retention benefits over purely digital approaches. Specifically, we will merge humour-driven and game-based approaches into a novel highly stimulating and fun-to-work-with educational material that prepares students in a strongly inquisitive state which is the ideal starting point for an encounter with a minituarized photonics laboratory - the Quantenkoffer. The PHONQUEE project will contribute to the creation of awareness, fascination, and understanding of quantum physics.

Q 3.8 Mon 16:30 P

Lasersystem for Control of Magnsium Atoms — •Lennart Guth, Philip Kiefer, Deviprasath Palani, Florian Hasse, Ulrich Warring, and Tobias Schätz — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Trapped ions present a promising platform for quantum simulations and computations. High fidelity control of this platform requires versatile and robust laser systems with narrow bandwidth and a high level of power and intensity stability. The latest systems are based on vertical external-cavity surface-emitting lasers(VECSEL)[1] in the near-infrared. The light is sent into two modular-built frequency doubling stages: (i)a lithium triborate cavity and (ii)a beta barium borate cavity to generate the required ultra-violet light. Here, we present benchmark measurements and demonstrate the performance for photoionization($\lambda \approx 1140$nm, P=1.7W) and sideband cooling($\lambda \approx 1120$nm, P> 3W, linewidth on short time scales $\nu \simeq 0.6$MHz) of magnesium ions.

[1]Burd, S. et al.(2016), VECSEL systems for generation and manipulation of trapped magnesium ions, Optica Vol. 3, Issue 12, pp. 1294-1299 (2016)

Q 3.9 Mon 16:30 P

Fluorescent Silica Aerogels for Random Lasing — •Matthias F. Kestler, Theobald Lohmüller, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Nano-Institute Munich and Department of Physics, Ludwig-Maximilians-Universität (LMU), Königinstr. 10, 80539 Munich, Germany

Aerogels are translucent, low density materials that display a high surface-to-volume ratio and an extremely low thermal conductivity. Being a porous network of colloidal particles, they scatter light at visible wavelengths. Furthermore, the aerogel matrix can be doped with fluorescent dyes or nanoparticles, which enables their wider use for optical applications such as random lasing. Here, we report on the synthesis of fluorescent silica aerogels by supercritical drying of dye-doped liquid gels. By our refined process, we obtain large amorphous samples with micrometer-sized pores, where scattering events lead to closed photon paths that can act as micrometer range cavities. We analyze the corresponding photoluminescence, amplified stimulated emission and random lasing spectra that are obtained for different dye-loaded aerogel samples. In the case of random lasing, we observe that the extraordinary thermal stability of aerogels benefits the use of high laser pumping energies without visible sample degradation.

Q 3.10 Mon 16:30 P

Terahertz spectroscopy with undetected photons — •Mirco Kutas[1,2], Björn Haase[1,2], Jens Klier[1], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Center for Materials Characterization and Testing, Fraunhofer ITWM, Kaiserslautern, Germany — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), Germany

Terahertz technology has proven its applicability to scientific and industrial tasks, but generation and detection of terahertz waves is often still technically complex. New quantum optical concepts provide highly attractive alternatives for the access to this spectral range. By using nonlinear interferometry, it is possible to transfer the photon properties after interaction with the sample to visible photons. As a result, the detection can be realized by widely available and highly developed CMOS sensors without the need of cooling or expensive pulsed lasers. We report on the demonstration of spectroscopy in the terahertz frequency range measuring absorption features of chemicals by only detecting visible photons [1].

[1] Kutas et al., Optica 8(4), 438-441 (2021)

Q 4: Precision spectroscopy of atoms and ions (joint session A/Q)

Time: Monday 16:30–18:30 Location: P

Q 4.1 Mon 16:30 P

Interorbital interactions in an SU(2)⊗SU(6)-symmetric Fermi-Fermi mixture — •Koen Sponselee[1], Benjamin Abeln[1], Marcel Diem[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, Germany — [2]Institute for Laser Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We characterise the *s*-wave interactions in interorbital ^{171}Yb-^{173}Yb Fermi-Fermi mixtures [1], where either ^{171}Yb is excited to the $^3P_0$ state while leaving ^{173}Yb in the ground state, or vice versa.

Using high-resolution clock spectroscopy, we measure the elastic scattering lengths and directly show the SU(2)⊗SU(6) symmetry of both interisotope interactions, which turn out to be attractive and similar. We further measure losses in these interorbital Fermi-Fermi mixtures and observe a difference of about two orders of magnitude between both interisotope interactions.

Along with other known $^1S_0$-$^3P_0$ state interactions of ytterbium, these measurements can be used as a benchmark for future ground-excited state Yb_2 molecular potential models.

This work is supported by the DFG within the SFB 925.

[1] B. Abeln, K. Sponselee, M. Diem, N. Pintul, K. Sengstock, and C. Becker, Phys. Rev. A **103**, 033315 (2021)

Q 4.2 Mon 16:30 P

Electronic structure of superheavy element ions from ab initio calculations — •Harry Ramanantoanina[1], Anastasia Borschevsky[2], Michael Block[3], and Mustapha Laatiaoui[1] — [1]Johannes Gutenberg-Universität Mainz, Deutschland — [2]University of Groningen, The Netherlands — [3]GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Deutschland

Within the framework of the recent Laser Resonance Chromatography (LRC) project, we are developing a theoretical approach to study the properties of superheavy elements ions. In this context, we use a fully relativistic model based on the 4-component Dirac Hamiltonian and multireference configuration interaction method to deal with the electronic structure and spectroscopic properties. In this presentation, we are reporting our first results of Lr+ (Z = 103), Rf+ (Z = 104) and Db+ (Z = 105). To validate the theoretical method, we have also calculated the energy spectrum of Lu+, Hf+ and Ta+, which are the lighter element homologue of the investigated superheavy ions, and we have compared the theoretical results with experimental data. Overall, the calculated energy levels and spectroscopic properties were in good agreement with the experimental data, confirming the suitability of the theoretical approach for this study and allowing us to expect good quality of the prediction for superheavy ions. The theoretical results are further discussed in terms of optical pumping schemes of metastable electronic states of the superheavy ions, very relevant for setting up future LRC experiments. This study is supported by the European Research Council (ERC) (Grant Agreement No. 819957).

Q 4.3 Mon 16:30 P

Current status of the Al^+ ion clock at PTB — •Fabian Dawel[1,2], Johannes Kramer[1,2], Steven A. King[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1,2], Stephan Hannig[1,2,3], Kai Dietze[1,2], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover — [3]DLR, Institut für Satellengeodäsie und Inertialsensorik (DLR-SI)

Since 1967 time is defined via a hyperfine transition in caesium-133. Optical clocks offer advantages in terms of statistical and systematic uncertainties over microwave clocks. A particularly promising candidate is the transition $^1S_0 \rightarrow {}^3P_0$ of $^{27}Al^+$, with advantageous atomic properties resulting in small uncertainties in magnetic, electric and black-body shifts. Here we review the design and operation of the $^{27}Al^+$ clock at PTB. In our clock implementation, Al^+ is co trapped with $^{40}Ca^+$ in a linear Paul trap. The working principle of quantum logic spectroscopy and a lifetime-limited excitation rabi cycle on the Al^+ logic transition is demonstrated. We will present an evaluation of systematic frequency shifts using the more sensitive Ca^+ as a proxy. All investigated shifts have an uncertainty below 10^{-18}. First measurements on the Al^+ clock transition will be presented with a power-broadened linewidth of 48 Hz.

Q 4.4 Mon 16:30 P

Measurement of Magnetic Moments in Heavy, Highly Charged Ions With Laser-Microwave Double-Resonance Spectroscoypy — •Khwaish Anjum[1,2], Patrick Baus[3], Gerhard Birkl[3], Manasa Chambath[1,4], Kanika[1,5], Jeffrey Klimes[1,5,6], Wolfgang Quint[1,5], and Manuel Vogel[1] — [1]GSI Helmholtzzentrum für Schwerionenforschung — [2]Delhi Technology University — [3]Institute for Applied Physics, TU Darmstadt — [4]Amrita Vishwa Vidyapeetham — [5]Heidelberg Graduate School for Fundamental Physics — [6]Max Planck Institute for Nuclear Physics

The ARTEMIS Penning trap will use laser-microwave double-resonance spectroscopy to measure the intrinsic magnetic moments of both electrons and nuclei in heavy, highly charged ions (HCIs). The (hyper)fine and Zeeman transitions of such HCIs in ARTEMIS are in the optical or microwave regimes respectively. A closed optical cycle probes successful induction of spin flips by microwave stimulus.

The spectroscopy trap of ARTEMIS uses a half-open design with a transparent, conductive endcap. This enables ≈ 2 sr conical access to the trap center for irradiation and detection of fluorescent light. This is more than an order of magnitude greater than conventional cylindrical designs with similar harmonicity and tunability. On the opposite side, cooled ion bunches are injected from an adjacent trap, where they are created by electron impact ionization.

Currently, ARTEMIS is working on systematics measurements with boron-like Ar^{13+} and preparing for capture of heavy HCIs such as hydrogen-like Bi^{82+} from the HITRAP facility at GSI.

Q 4.5 Mon 16:30 P

A New Experiment for the Measurements of the Nuclear Magnetic Moment of $^3He^{2+}$ and the Ground-State Hyperfine Splitting of $^3He^+$ — •Annabelle Kaiser[1,2], Antonia Schneider[1], Bastian Sikora[1], Andreas Mooser[1], Stefan Dickopf[1,2], Marius Müller[1], Alexander Rischka[1], Stefan Ulmer[3], Jochen Walz[4,5], Zoltan Harman[1], Christoph H. Keitel[1], and Klaus Blaum[1] — [1]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [2]Heidelberg University, Heidelberg, Germany — [3]RIKEN, Wako, Japan — [4]Johannes Gutenberg-University, Mainz, Germany — [5]Helmholtz-Institute Mainz, Germany

The Heidelberg ^{3}He-experiment is aiming at the first direct high-precision measurement of the nuclear magnetic moment of $^3He^{2+}$ with a relative uncertainty on the 10^{-9} level and an improved measurement of the ground-state hyperfine splitting of $^3He^+$ by at least one order of magnitude. The helion nuclear magnetic moment is an important parameter for the development of hyperpolarized ^{3}He-NMR-probes for absolute magnetometry. The HFS measurement of $^3He^+$ is sensitive to nuclear structure effects and would give information about such effects in a three-nucleon system. For the $^3He^+$ and $^3He^{2+}$ measurements, two and four Penning trap setups were designed respectively, and similar techniques as already demonstrated in proton and antiproton magnetic moment measurements [1,2] are going to be applied. The current status of the experiment is presented.

[1] Schneider et al., Science Vol 358, 1081 (2017)

[2] Smorra et al., Nature, Vol 550, 371 (2017)

Q 4.6 Mon 16:30 P

Self-injection locked laser system for quantum logic and entanglement operations — •Ludwig Krinner[1,2], Lennart Pelzer[1], Kai Dietze[1], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116, Braunschweig — [2]Leibniz Universität Hannover, Welfengarten 1, 30167, Hannover

While diode lasers have become a prevalent tool for the cooling and coherent manipulation of atoms and ions, they typically show an inconvenient and sometimes even problematic amount of noise at Fourier frequencies of a few hundred kilohertz to a few megahertz. Especially in the case of trapped ions, this coincides with the motional frequencies of the secular motion. Excess noise can compromise coherent manipulation of sideband transitions, such as sideband cooling or entanglement operations by incoherently driving the much stronger carrier transitions. We demonstrate a self-injection locked laser system using the transmitted light of a medium-finesse linear cavity. The system can easily be adapted from an existing standard Pound-Drever-Hall laser locking scheme using a linear cavity, as opposed to Y-shaped or bow-tie cavities, which are usually employed for self-injection locking. We demonstrate the excellent suppression of high frequency noise by measuring incoherent excitation 0.3 . . . 4 MHz away from the carrier transition using a single trapped $^{40}Ca^+$ ion as a probe, finding an inferred reduction of over 30 dB in noise spectral density compared to a state-of-the art external-cavity diode laser.

Q 4.7 Mon 16:30 P

Laser photodetachment spectroscopy in an MR-ToF device — •David Leimbach for the GANDALPH and MIRACLS collaborations — Department of Physics, University of Gothenburg, Gothenburg, Sweden — CERN, Geneva, Switzerland — Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany

The electron affinity (EA) is the energy released when an additional electron is bound to a neutral atom, creating a negative ion. Due to the lack of a long-range Coulomb attraction, the EA is dominated by electron-correlation effects. A prime example for the importance of the accurate description of the electron correlation is the theoretical calculation of the specific mass shift, which is an indispensable ingredient when extracting nuclear charge radii from laser-spectroscopy work. Although the isotope shift (IS) in the EA of the stable chlorine isotopes has been determined experimentally, recent calculations improved the theoretical precision beyond the measurement precision. By using a MR-ToF device we are able to perform laser photodetachment spectroscopy while reusing the ion beam, thereby increasing the efficiency in the detection method. Additionally, we will extend this type of studies to long-lived radionuclides for the first time by determining the IS of 36Cl. This novel approach could be applied to IS measurements of short-lived isotopes as well as EA determination of sparsely produced and eventually superheavy radioelements. We will present the technique, developments and status of the experimental campaign.

Q 4.8 Mon 16:30 P

Current status of the transportable ^{87}Sr lattice clock at PTB — •Tim Lücke, Ingo Nosske, Chetan Vishwakarma, Sofia Herbers, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The prospect of direct observation and accurate determination of gravitational potential differences led to great efforts to develop transportable optical clocks within the last decade. At PTB, we are operating a ^{87}Sr lattice clock in an air-conditioned car trailer for chronometric leveling. Here we present a recent uncertainty evaluation of our clock reaching the very low 10^{-17} regime. Furthermore, we explore future measures to reduce its uncertainty into the 10^{-18} regime including a new physics package allowing the transport of the atoms into a cryogenic interrogation chamber by a moving lattice.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 Terra Q and Project-ID 390837967 - EXC-2123 QuantumFrontiers.

Q 4.9 Mon 16:30 P

Interrogating the temporal coherence of EUV frequency combs with highly charged ions — •Chunhai Lyu, Stefano M. Cavaletto, Christoph H. Keitel, and Zoltán Harman — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

An extreme-ultraviolet (EUV) frequency comb is usually generated via intra-cavity high-order harmonic generation of an infrared (IR) frequency comb. However, whether the temporal coherence of the IR frequency comb is preserved in the corresponding EUV frequency comb is still under debate. Here, we put forward a scheme to directly infer the temporal coherence of EUV frequency combs via spectroscopy of highly charged Mg-like ions. The fluctuations of the carrier-envelope phase between EUV pulses is modelled as a random walk process. Based on numerical simulations, we show that the coherence time of the EUV frequency comb can be determined from the excitation spectrum of given ionic transitions. This scheme will provide a verification of the temporal coherence of an EUV frequency comb at timescales several orders of magnitude longer than current state of the art, and at the same time will enable high-precision spectroscopy of EUV transitions down to the 15th digit.

[1]. Phys. Rev. Lett. 98, 070801 (2020).

Q 4.10 Mon 16:30 P

Construction and tests of image-current detection systems for the transportable antiproton trap STEP. — •Fatma Abbass[1], Christian Will[1], Daniel Popper[1], Matthew Bohman[1,7], Markus Wiesinger[1], Markus Fleck[7], Jack Devlin[2,7], Stefan Erlewein[2,7], Julia Jaeger[2,7], Barbara Latacz[7], Peter Micke[7], Klaus Blaum[3], Christian Ospelkaus[4], Wolfgang Quint[6], Yasuyuki Matsuda[5], Yasunori Yamazaki[7], Jochen Walz[1,8], Stefan Ulmer[7], and Christian Smorra[1] — [1]nstitut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, D-55128 Mainz, Germany — [2]CERN, 1211 Geneva, Switzerland — [3]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [4]Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany — [5])Graduate School of Arts and Sciences, University of Tokyo, Tokyo 153-8902, Japan — [6]GSI Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt, Germany — [7]RIKEN, Fundamental Symmetries Laboratory, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan — [8])Helmholtz-Institut Mainz, D-55099 Mainz, Germany

We develop a Penning trap image current detection systems including a cyclotron detection system. The image current detection systems which I developed and tested are made up of superconducting toroidal coils and cryogenic amplifiers. As a result, I was able to achieve a higher Q-value with toroidal coils than we had previously achieved using solenoids.

Q 4.11 Mon 16:30 P

High-Resolution Electron-Ion Collision Spectroscopy with Slow Cooled Pb^{78+} Ions in the CRYRING@ESR Storage Ring — •Sebastian Fuchs[1,2], Carsten Brandau[1,3], Esther Menz[3,4,5], Michael Lestinsky[3], Alexander Borovik Jr[1], Yanning Zhang[6], Zoran Andelkovic[3], Frank Herfurth[2], Christophor Kozhuharov[3], Claude Krantz[3], Uwe Spillmann[3], Markus Steck[3], Gleb Vorobyev[3], Dariusz Banaś[7], Michael Fogle[8], Stephan Fritzsche[4,5], Eva Lindroth[9], Xinwen Ma[10], Alfred Müller[1], Reinhold Schuch[9], Andrey Surzhykov[11,12], Martino Trassinelli[13], Thomas Stöhlker[3,4,5], Zoltan Harman[14], and Stefan Schippers[1,2] — [1]JLU Gießen — [2]HFHF Campus Gießen — [3]GSI — [4]HI Jena — [5]FSU Jena — [6]Xi'an Jiaotong University — [7]JKU Kielce — [8]Auburn University — [9]Stockholm University — [10]IMPCAS Lanzhou — [11]TU Braunschweig — [12]PTB — [13]UPMC Paris — [14]MPIK

The experimental technique of dielectronic recombination (DR) collision spectroscopy is a very successful approach for studying the properties of ions. Due to its versatility and the high experimental precision DR spectroscopy plays an important role in the physics program of the SPARC collaboration. CRYRING@ESR is particularly attractive for DR studies, since it is equipped with an electron cooler that provides an ultra-cold electron beam promising highest experimental resolving power. Here, we report on recent results from the first DR experiment with highly charged ions in the heavy-ion storage ring CRYRING@ESR of the international FAIR facility in Darmstadt.

Q 4.12 Mon 16:30 P

Towards direct optical excitation of the nuclear clock isomer ^{229m}Th — •Johannes Thielking, Maksim V. Okhapkin, Jascha Zander, Johannes Tiedau, Gregor Zitzer, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

The transition of the ^{229}Th nucleus between its ground state and its uniquely low-lying isomer at about 8 eV has been proposed as a frequency reference for a highly precise type of optical clock [1]. Although several advances have been made in determining the transition energy and nuclear properties [2], its optical excitation is still pending. To this end, we are currently developing a vacuum ultraviolet (VUV) laser system based on resonance enhanced four-wave difference mixing in xenon. The mixing process is driven by two pulsed dye laser amplifiers with a pulse duration of 10 ns. The amplifiers are seeded with cw ring lasers to achieve a Fourier transform limited bandwidth. The laser system provides VUV pulses with photon numbers of about 10^{13} per pulse and a broad tunability that covers the current uncertainty range of the nuclear excitation energy. Here we will report on the current status of the laser development, as well as future experiments to excite the isomeric state in trapped ions and a Th-doped crystal.

[1] E. Peik, Chr. Tamm, Europhys. Lett. 61, 181 (2003).
[2] K. Beeks et al., Nature Reviews Physics 3(4), 238-248 (2021).

Q 4.13 Mon 16:30 P

High-Precision Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at Alphatrap — •Charlotte M. König, Fabian Heisse, Jonathan Morgner, Tim Sailer, Bingsheng Tu, Klaus Blaum, and Sven Sturm — Max-Planck-Institut für Kernphysik, 69117 Heidelberg

As the simplest molecules, molecular hydrogen ions (MHI) are an excellent system for testing QED. In collaboration with the group of Stephan Schiller (Heinrich-Heine-University Düsseldorf), we plan to perform high-precision spectroscopy on single MHI in the Penning-trap setup of Alphatrap [1]. The first measurements, in the microwave and MHz regime, will investigate the hyperfine structure of HD^+. This will allow extracting the bound g-factors of the constituent particles and coefficients of the hyperfine hamiltonian, from which rovibrational laser spectroscopy performed on this ion species can benefit [2].

In the future, we aim to extend our methods to single ion rovibrational laser spectroscopy of H_2^+ at IR wavelengths enabling the ultra precise determination of fundamental constants, such as $m_\mathrm{p}/m_\mathrm{e}$ [3]. The development of the required techniques for this measurement will be an important step towards spectroscopy of an antimatter $\overline{\mathrm{H}}_2^-$ ion for tests of matter-antimatter symmetry [4]. In this contribution, I will present an overview of the experimental setup and the measurement schemes.

[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425-1491 (2019)
[2] I. V. Kortunov, *et al.*, Nature Physics **17**, 569 573 (2021)
[3] J.-Ph. Karr, *et al.*, Phys. Rev. **A94**, 050501(R) (2016)
[4] E. Myers, Phys. Rev. **A98**, 010101(R) (2018)

Q 4.14 Mon 16:30 P

A cryogenic Penning trap system for sympathetic laser cooling of atomic ions and protons — •Julia-Aileen Coenders[1], Johannes Mielke[1], Teresa Meiners[1], Malte Niemann[1], Amado Bautista-Salvador[2], Ralf Lehnert[3], Juan Manuel Cornejo[1], Stefan Ulmer[4], 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]Indiana University Center for Spacetime Symmetries, Bloomington, IN 47405, USA — [4]Ulmer Fundamental Symmetries Laboratiory, RIKEN, Wako, Saitama 351-0198, Japan

High precision measurements 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, present experiments fight against systematic uncertainties depending on the motional amplitude of the particle. To this end, experimental schemes based on sympathetic cooling of single (anti-)protons through co-trapped laser cooled atomic ions can contribute to the ongoing strive for improved precision through fast preparation times and low particle temperatures.

Here we present a cryogenic Penning trap system for free space coupling of two particles via Coulomb interaction in an engineered double-well potential. We report on recent results of thermometry measurements with $^9Be^+$ ions and sideband cooling of the same. Prospects for sympathetic cooling of protons in a micro-coupling trap will be discussed.

Q 4.15 Mon 16:30 P

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian J. Zawierucha[1], Till Rehmert[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

High precision spectroscopy of trapped molecular ions constitutes a promising tool for the study of fundamental physics. Possible applications include the search for a variation of fundamental constants and measurement of the electric dipole moment of the electron.

Compared to atoms, molecules offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well suited for those applications.

However, the additional rotational and vibrational degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, optical pumping and state detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy.

In addition to the molecular ion, a well-controllable atomic ion is co-trapped, coupling strongly to the molecule via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection.

Here, we present the status of our experiment, aiming at high precision quantum logic spectroscopy of molecular oxygen ions.

Q 4.16 Mon 16:30 P

Experimental and simulation progress of the Laser Resonance Chromatography technique — •EunKang Kim[1,2], Michael Block[1,2,3], Mustapha Laatiaoui[1,2], Harry Ramanantoanina[1,2], Elisabeth Rickert[1,2,3], Elisa Romero Romero[1,2,3], Philipp Sikora[1], and Jonas Schneider[1] — [1]Department Chemie, Johannes Gutenberg-Universität, Fritz-Strassmann Weg 2, 55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, Staudingerweg 18, 55128 Mainz, Germany — [3]GSI, Planckstraße 1, 64291 Darmstadt, Germany

The superheavy elements present an experimental challenge as they exhibit low production yields and very short half-lives, and their atomic structure is barely known. Traditional techniques like monitoring fluorescence are no longer suitable as they lack the sensitivity required for superheavy element research. To overcome this challenge, a new technique called *Laser Resonance Chromatography* (LRC) is proposed for probing the heaviest product ions in situ. In this contribution, I will explain the principle, configuration, simulation and progress of the LRC experiment. This work is supported by the European Research Council (ERC) (Grant Agreement No. 819957).

Q 4.17 Mon 16:30 P

Two-loop QED corrections to the bound-electron g-factor: M-term — •Bastian Sikora[1], Vladimir A. Yerokhin[2], Christoph H. Keitel[1], and Zoltán Harman[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia

The theoretical uncertainty of the bound-electron g-factor in high-Z hydrogenlike ions is dominated by uncalculated Feynman diagrams with two self-energy loops. In our previous study, we have obtained full results for the loop-after-loop diagrams, and partial results for the nested and overlapping loop diagrams by taking into acount the Coulomb interaction in intermediate states to zero and first order [1].

In this work, we present our results for the so-called M-term contribution. This corresponds to the ultraviolet finite part of nested and overlapping loop diagrams in which the Coulomb interaction in intermediate states is taken into account to all orders.

Our results will be highly relevant for planned near future tests of QED in high-Z ions as well as for an independent determination of the fine-structure constant α from the bound-electron g-factor.

[1] B. Sikora, V. A. Yerokhin, N. S. Oreshkina et al., Phys. Rev. Research 2, 012002(R) (2020).

Q 4.18 Mon 16:30 P

Theory of the Zeeman and hyperfine splitting of the $^3He^+$ ion — •Bastian Sikora, Zoltán Harman, Natalia S. Oreshkina, Igor Valuev, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

When exposed to an external magnetic field, the combined hyperfine and Zeeman effect leads to a splitting of the ground state of the $^3He^+$ ion into four sublevels. Measurements of transition frequencies [1] between these sublevels allow the determination of the bound electron's g-factor, the ground-state hyperfine splitting in the absence of an external magnetic field as well as the magnetic moment of the nucleus, shielded by the presence of the bound electron.

We present the theoretical calculation of the shielding constant which is required to extract the magnetic moment of the bare nucleus. Furthermore, we present the theory of the ground-state hyperfine splitting and the bound-electron g-factor. The theoretical accuracy of the bound-electron g-factor is limited by the accuracy of the fine-structure constant α. Furthermore, assuming the correctness of theory of hyperfine splitting, one can extract the nuclear Zemach radius from the experimental hyperfine splitting value.

[1] A. Mooser, A. Rischka, A. Schneider, et al., J. Phys.: Conf. Ser. 1138, 012004 (2018)

Q 4.19 Mon 16:30 P

Engineering Atom-Photon and Atom-Atom Interactions with Nano-photonics — •Artur Skljarow[1], Benyamin Shnirman[1], Harald Kübler[1], Hadiseh Alaeian[2], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Germany — [2]Departments of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana, USA

We study an integrated silicon photonic chip, composed of several subwavelength ridge and slot waveguides, immersed in a micro-cell with rubidium vapor. With the help of a two-photon excitation, we observe that the guided mode transmission spectrum gets modified when the photonic mode is coupled to rubidium atoms through its evanescent tail. We also investigate the coupling of atomic vapor to slot waveguides. The slot mode constrains the probed atomic density to an effective one-dimensional system. This is interesting to study the collective atom-atom interactions in 1D. We developed a Monte-Carlo simulation method to predict and interpret the measured data. In addition to the silicon plattform we are also fabricating and investigating Nano-devices made of silicon nitride. In order to reach the interesting quantum regime with thermal vapors we plan to create a non-linearity by enhancing the light field with a photonic crystal cavity. We have fabricated these devices with a novel underetching technique where specified regions with the Si3N4 PhCs are suspended in air. This technique allows direct coupling into the cavity via the waveguide and enables a more versatile design of the chip.

Q 4.20 Mon 16:30 P

High-Resolution Microcalorimeter Measurement of X-Ray Transitions in He-like Uranium at CRYRING@ESR — •Felix Martin Kröger[1,2,3], Steffen Allgeier[4], Andreas Fleischmann[4], Marvin Friedrich[4], Alexandre Gumberidze[3], Marc Oliver Herdrich[1,2,3], Daniel Hengstler[4], Patricia Kuntz[4], Michael Lestinsky[3], Bastian Löher[3], Esther Babette Menz[1,2,3], Philip Pfäfflein[1,2,3], Uwe Spillmann[3], Günter Weber[1,2,3], Christian Enss[4], and Thomas Stöhlker[1,2,3] — [1]HI Jena, Fröbelstieg 3, Jena, Germany — [2]IOQ Jena, FSU Jena, Max-Wien-Platz 1, Jena, Germany — [3]GSI, Planckstraße 1, Darmstadt, Germany — [4]KIP, RKU Heidelberg, Im Neuenheimer Feld 227, Heidelberg, Germany

We present the first application of metallic magnetic calorimeter detectors for high resolution X-ray spectroscopy at the electron cooler of CRYRING@ESR, the low energy storage ring of GSI, Darmstadt. Within the experiment, X-ray radiation emitted as a result of recombination events between the cooler electrons and a stored beam of U^{91+} ions was studied. For this purpose, two maXs detectors were positioned under observation angles of 0° and 180° with respect to the ion beam axis. This report will focus on details of the experimental setup, its performance and its integration into the storage ring environment.

This research has been conducted in the framework of the SPARC collaboration, experiment E138 of FAIR Phase-0 supported by GSI. We acknowledge substantial support by ErUM-FSP APPA (BMBF n° 05P19SJFAA).

Q 4.21 Mon 16:30 P

maXs100: A 64-pixel Metallic Magnetic Calorimeter Array for the Spectroscopy of Highly-Charged Heavy Ions — •S. Allgeier[1], M. Friedrich[1], A. Gumberidze[2], M.-O. Herdrich[2,3,4], D. Hengstler[1], F. M. Kröger[2,3,4], P. Kuntz[1], A. Fleischmann[1], M. Lestinsky[2], E. B. Menz[2,3,4], Ph. Pfäfflein[2,3,4], U. Spillmann[2], B. Zhu[4], G. Weber[2,3,4], Th. Stöhlker[2,3,4], and Ch. Enss[1] — [1]KIP, Heidelberg University — [2]GSI, Darmstadt — [3]IOQ, Jena University — [4]HI Jena

Metallic magnetic calorimeters (MMCs) are energy-dispersive X-ray detectors which provide an excellent energy resolution over a large dynamic range combined with a very good linearity. MMCs are operated at millikelvin temperatures and convert the energy of each incident photon into a temperature pulse which is measured by a paramagnetic temperature sensor. The resulting change of magnetisation is read out by a SQUID magnetometer. For the investigation of electron transitions in $\mathbf{U^{90+}}$ at CRYRING@FAIR we developed the 2-dimensional maXs-100 detector array within the framework of the SPARC collaboration. It features 8x8 pixels with a detection area of 1 cm^2 and 50 μm thick absorbers made of gold, resulting in a stopping power of 40 % at 100 keV. An energy resolution of 40 eV at 60 keV was demonstrated in co-added spectra. The non-linearity of the detector system including the read-out chain was shown to be in the range of 0.2 % @ 136 keV. We will discuss the cryogenic setup of the two detector systems used during the beam time in April 2021, as well as the properties of the maXs-100 detector array including a sub-eV absolute energy calibration.

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

Time: Tuesday 14:00–15:30 Location: H1

Invited Talk Q 5.1 Tue 14:00 H1

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.

Invited Talk Q 5.2 Tue 14:30 H1

Dynamics of a mobile hole in a Hubbard antiferromagnet — •Martin Lebrat, Geoffrey Ji, Muqing Xu, Lev Haldar Kendrick, Christie S. Chiu, Justus C. Brüggenjürgen, Daniel Greif, Annabelle Bohrdt, Fabian Grusdt, Eugene Demler, 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.

Invited Talk Q 5.3 Tue 15:00 H1

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 6: Quantum Gases and Matter Waves (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

Q 6.1 Tue 16:30 P

Coherent and dephasing spectroscopy for single-impurity probing of an ultracold bath — •Daniel Adam, Quentin Bouton, Jens Nettersheim, Sabrina Burgardt, and Artur Widera — Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Individual impurities immersed in a gas form a paradigm of open quantum systems. Especially, nondestructive quantum probing has gained significant interest in recent years. Here, we report on probing the coherent and dephasing dynamics of single impurities in a bath to extract information about the impurity's environment. Experimentally, we immerse single Cs atoms into a Rb bath and perform a Ramsey spectroscopy on the Cs clock transition. The Ramsey fringe is modified by a differential shift of the collisional (kinetic) energy when the two Cs states superposed interact with the Rb bath. The shift is affected by the bath density and the details of the Rb-Cs interspecies scattering length. By preparing the system close to a low-magnetic field Feshbach resonance, we enhance the dependence on the temperature due to the strong dependence of the s-wave scattering length on the collisional energy. By analyzing the coherent phase evolution and decay of the Ramsey fringe contrast, we probe the Rb cloud's density and temperature with minimal perturbation of the cloud.

Q 6.2 Tue 16:30 P

Compressibility of a two-dimensional homogeneous Bose gas in a box — •Leon Espert Miranda, Erik Busley, Kirankumar Umesh, Frank Vewinger, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Bonn, Germany

Homogeneous quantum gases enable studies of the collective behavior in quantum materials ranging from superfluids to neutron stars. A particular example for quantum matter are Bose-Einstein condensates (BEC). Here we realize an optical quantum gas in a box potential inside a nanostructured microcavity and observe BEC in the finite-size homogeneous 2D system. By exerting a force on the photon gas, we probe its compressibility and equation of state, demonstrating the physical significance of the infinitely compressible BEC in an ideal gas.

Q 6.3 Tue 16:30 P

Optical Potentials based on Conical Refraction for Bose-Einstein Condensates — •Dominik Pfeiffer, Ludwig Lind, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Optical trapping and guiding potentials based on conical refraction (CR) in a biaxial crystal present a versatile tool for the manipulation of atomic matter waves in atomtronics circuits. Based on the specific properties of CR, we generate a three-dimensional dark focus optical trapping potential for ultra-cold atoms and Bose-Einstein condensates. This 'optical bottle' is created by a single blue-detuned laser beam and gives full 3D confinement of cold atoms. We present the experimental implementation and give a detailed analysis of the trapping properties.

Q 6.4 Tue 16:30 P

Exploring the nature of the steady state of non-interacting fermionic atoms coupled to a dissipative cavity — •Jeannette De Marco, Catalin Halati, Ameneh Sheikhan, and Corinna Kollath — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We investigate the influence of a strong symmetry of the Liouvillian on the nature of the steady state for a non-interacting fermionic chain globally coupled to a lossy optical cavity. Using a newly developed many-body adiabatic elimination technique, we capture the dissipative nature of the quantum light field as well as the global coupling to the cavity mode beyond the mean-field ansatz. For finite systems, we show that the existence of a strong symmetry leads to multiple steady state solutions and we investigate how the dissipative phase transition to self-organized states occurs for the different symmetry sectors.

Q 6.5 Tue 16:30 P

Transport through a lattice with a local particle loss — •Anne-Maria Visuri[1], Corinna Kollath[1], and Thierry Giamarchi[2] — [1]Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Department of Quantum Matter Physics, University of Geneva, 24 quai Ernest-Ansermet, 1211 Geneva, Switzerland

The effect of dissipation on transport is relevant for the fundamental understanding of quantum mechanics as well as the development of quantum technologies. Dissipative transport has recently been probed in experiments with ultracold atoms, where one can engineer controlled dissipation mechanisms in the form of a particle losses. We study transport through a chain of coupled sites, which is connected to reservoirs at both ends, and analyze the effect of a local particle loss on transport. The reservoirs are described as free spinless fermions. We characterize the particle transport by calculating the conductance, loss current, and particle density in the steady state using the Keldysh formalism for open quantum systems. We find that for specific values of the chemical potential in the lattice, transport is unaffected by the local particle loss. This is understood by considering the single-particle eigenstates in a lattice with open boundary conditions.

Q 6.6 Tue 16:30 P

Developing MPS-methods for a Fermi-Hubbard model coupled to a dissipative photonic mode — •Luisa Tolle — Physikalisches Institut, University of Bonn, Germany

We present the current status of the development of a numerical exact method describing the time evolution of an interacting Fermi-Hubbard chain coupled globally to a dissipative photonic mode.

A physical realization of the considered model is e.g. an ultracold atomic gas in an optical lattice coupled to a photonic mode of an optical cavity. In order to capture the open nature of the photons in the time evolution we perform the purification on the density matrix. In this context we extend time-dependent matrix product techniques to include the global coupling of the photonic mode to the interacting atoms and deal with the very large Hilbert space of the photonic mode. This allows to study the long-time dynamics of the system towards the self-organization transition.

Q 6.7 Tue 16:30 P

Multi-axis and high precision rotation sensing with Bose-Einstein condensates — •Sven Abend[1], Christian Schubert[1,2], Matthias Gersemann[1], Martina Gebbe[3], Dennis Schlippert[1], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Satellitengeodäsie und Inertialsensorik — [3]ZARM, Universität Bremen

Atom interferometers are versatile tools to measure inertial forces and were utilised as accurate gravimeters. Exploiting the Sagnac effect by enclosing an area with matterwaves enables rotation measurements. We present a concept for a multi-loop atom interferometer with a scalable area formed by light pulses, making use of twin-lattice atom interferometry.

Addionally, we create two simultaneous atom interferometers out of a single Bose-Einstein condensate (BEC), to differntiate between rotations and accelerations. Our method exploits the precise motion control of BECs combined with the precise momentum transfer by double Bragg diffraction for interferometry. Consequently, the scheme avoids the complexity of two BEC sources. We show our experimental results and discuss the extension to a six-axis quantum inertial measurement unit.

This work is supported by the Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under Grand No. DLR 50RK1957 (QGyro).

Q 6.8 Tue 16:30 P

Bound Pairs Scattering off a Floquet Driven Impurity — •Friedrich Hübner, Ameneh Sheikhan, and Corinna Kollath — HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

We study how bound pairs of Fermions in a Fermi-Hubbard chain scatter off a driven impurity which is a single site with a shaken chemical potential. We thereby extend the work of Thuberg et al. [1] who considered non-interacting single particles.

In the limit where the hopping parameter J is much smaller than the Hubbard interaction U – as long as U is not an integer multiple of the driving frequency ω – we can derive an effective Hamiltonian governing the motions of pairs by means of a Floquet-Schrieffer-Wolff transformation. From it we calculate the pair transmission through the impurity and compare it to the single particle transmission. We validate the result by exact diagonalization and find that it is still a good approximation for finite $J/|U|$ throughout the non-resonant case.

We also analytically study the resonant case where U is an integer multiple of ω which leads to pair breaking by absorbing energy from the drive. Contrary to our expectation we find that pair breaking is suppressed for $J \ll |U|$.

[1] D. Thuberg, S. Reyes, S. Eggert, PhysRevB.93.180301 (2016)

Q 6.9 Tue 16:30 P

Unsupervised machine learning of topological phase transitions from experimental data — •Niklas Käming[1], Anna Dawid[2,3], Korbinian Kottmann[3], Maciej Lewenstein[3,4], Klaus Sengstock[1,5,6], Alexandre Dauphin[3], and Christof Weitenberg[1,5] — [1]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland — [3]Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain — [4]ICREA, Pg. Lluís Campanys 23, 08010 Barcelona, Spain — [5]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [6]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Identifying phase transitions is one of the key challenges in quantum many-body physics. Recently, machine learning methods have been shown to be an alternative way of localising phase boundaries from noisy and imperfect data without the knowledge of the order parameter. Here, we apply different unsupervised machine learning techniques to experimental data from ultracold atoms. In this way, we obtain the topological phase diagram of the Haldane model in a completely unbiased fashion. We show that these methods can successfully be applied to experimental data at finite temperatures and to the data of Floquet systems when post-processing the data to a single micromotion phase.

Q 6.10 Tue 16:30 P

Mixing fermionic ^{6}Li impurities with a Bose-Einstein condensate of ^{133}Cs — •Binh Tran, Eleonora Lippi, Manuel Gerken, Michael Rautenberg, Marcia Kroker, Lauriane Chomaz, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Fermionic ^{6}Li impurities in a ^{133}Cs Bose-Einstein condensate (BEC) realize a very well controllable version of the Bose polaron, a quasi-particle emulating the Fröhlich polaron problem as known from solid-state physics. I will describe our upgraded scheme for trapping and combining degenerate gases of Li and Cs. We create a BEC of Cs atoms at high magnetic fields (>880 G), where a broad Feshbach resonance between Li and Cs allows to control the sign and the strength of interactions. By means of two crossed optical dipole traps of vastly different volumes, we make use of an efficient "dimple-trick" to increase the phase-space density, which we describe both theoretically and experimentally, before performing forced evaporative cooling. A tightly confining movable optical dipole trap of 880.25 nm wavelength, which realizes a tune-out wavelength for Cs, allows to store, move, and confine a Li cloud within a small volume of the Cs BEC without imposing any additional confinement to Cs.

Q 6.11 Tue 16:30 P

Time-domain optics for atomic quantum matter — •Simon Kanthak[1,2], Martina Gebbe[3], Matthias Gersemann[4], Sven Abend[4], Ernst M. Rasel[4], Markus Krutzik[1,2], and the QUANTUS team[1,2,3,4] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Quantenoptik, LU Hannover

We investigate time-domain optics for atomic quantum matter. Within a matter-wave analog of the thin-lens formalism, we study optical lenses of different shapes and refractive powers to precisely control the dispersion of Bose-Einstein condensates. Anharmonicities of the lensing potential are incorporated in the formalism with a decomposition of the center-of-mass motion and expansion of the atoms, allowing to probe the lensing potential with micrometer resolution. By arranging two lenses in time formed by the potentials of an optical dipole trap and an atom-chip trap, we realize a magneto-optical matter-wave telescope. We employ this hybrid telescope to manipulate the expansion and aspect ratio of the ensembles. The experimental results are compared to numerical simulations that involve Gaussian shaped potentials to accommodate lens shapes beyond the harmonic approximation.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under Grant No. 50WM1952 (QUANTUS-V-Fallturm).

Q 6.12 Tue 16:30 P

A new experiment for programmable quantum simulation using ultracold 6Li atoms — •Armin Schwierk, Tobias Hammel, Micha Bunjes, Maximilian Kaiser, Leo Walz, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Efficient quantum simulation using ultracold atoms is typically limited by a variety of experimental factors like available laser power or the numerical aperture of the objective. These factors strongly limit achievable cycle times to around a few seconds, posing a problem when high statistics and good control of the atoms are needed. We are building a new Lithium-6 experiment, with which we aim to reduce the cycle time to below one second. All parts of the apparatus will be build up from modular blocks to increase adaptability, stability and control over the system.

In this poster, we will present the current state of the development of the experiment. The design evolves around a small octagonal glass cell with a diameter of only 5cm and large optical access of up to 0.85NA vertically and 0.3NA horizontally. The small size of the glass cell enables the use of small and fast tuneable magnetic field coils close to the atoms, allowing versatile control of the magnetic fields. A high flux 2D-MOT as precooling stage will help in reducing the cycle times and in making the whole experiment a lot more compact with a distance of 30cm from 2D-MOT centre to the centre of the glass cell. With this new apparatus, we take a first step towards easily and versatile programmable quantum simulation.

Q 6.13 Tue 16:30 P

Few Fermions in optically rotating traps — •Philipp Lunt, Paul Hill, Diana Körner, Jonas Drotleff, Daniel Dux, Ralf Klemt, Selim Jochim, and Philipp Preiss — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

The formal equivalence of electrons in an external magnetic field and neutral atoms in rapidly rotating traps opens up new avenues to study fractional quantum hall physics with ultracold atomic gases.

In order to access the microscopic level of strongly correlated quantum hall states we build on our previously established experimental methods - the deterministic preparation of ultracold ^{6}Li few Fermion systems in low dimensions [1,2], as well as local observation of their correlation and entanglement properties on the single atom level [3].

Here, we present current experimental progress towards adiabatic preparation of deterministic few Fermion states in rapidly rotating optical potentials. We achieve rotation in an all-optically manner by interference of a Gaussian and Laguerre-Gaussian (LG) mode generated by a spatial light modulator [4]. In particular, we showcase the optical setup, which includes elaborate methods to cancel phase aberrations in order to meet the challenging requirement regarding the isotropy of the potential geometry.

[1] Serwane et al. Science 332 (6027), 336-338 [2] Bayha et al. Nature 587, 583-587 (2020) [3] Bergschneider et al. Nat. Phys. 15, 640-644 (2019) [4] Palm et al 2020 New J. Phys. 22 083037

Q 6.14 Tue 16:30 P

Numerical simulation of out of equilibrium dynamics of Dicke model — •Marcel Nitsch — Physikalisches Institut, University of

Bonn, Nussallee 12, 53115 Bonn, Germany

The time dependent matrix product state algorithms are strong tools to simulate the out of equilibrium dynamics of many body quantum systems. A new method was introduced to calculate the time evolution of a system represented by a matrix product state which is based on the Dirac-Frenkel time-dependent variational principle. Compared to the conventional time evolution using a Trotter-Suzuki splitting of the Hamiltonian, the new method promises more stable and more efficient calculations for systems with longer ranged interactions. In this poster I briefly explain the time-dependent variational principle method and present a comparison between both methods for the Dicke model. This model describes the behaviour of two-level atoms coupled to a cavity field. In the matrix product state formalism, this corresponds to a global one-to-all coupling.

Q 6.15 Tue 16:30 P

Observation of Cooper pairs in a few-body system — Marvin Holten, Luca Bayha, •Keerthan Subramanian, Sandra Brandstetter, Carl Heintze, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany

Recent advances in deterministic preparation of few-body systems have led to the observation of an emergence of a quantum phase transition [1] and single particle detection methods have resulted in the first observation of Pauli crystals [2] demonstrating correlations in a non-interacting system due to quantum statistics.

In this poster we present the first direct observation of Cooper pairs in a few-body system of ^{6}Li atoms. We deterministically prepare low entropy samples of a two-component Fermi gas in a 2D harmonic oscillator potential and directly observe the full spin and single particle resolved momentum distribution enabling us to extract correlation functions of any order. We demonstrate the crossover from no pairing to Cooper-pairing at the Fermi surface to softening of the Fermi surface and pairing at all momenta as the interaction is increased.

In the future we plan to extend our imaging scheme to obtain single atom resolved images of the in-situ cloud [3]. This would allow us to tackle questions related to 2D Fermi superfluids concerning the nature of the normal phase and pairing in spin-imbalanced systems.

[1] L. Bayha, et al. Nature 587.7835 (2020): 583-587.
[2] M. Holten, et al. Physical Review Letters 126.2 (2021): 020401
[3] L. Asteria, et al. arXiv:2104.10089 (2021).

Q 6.16 Tue 16:30 P

Realization of an anomalous Floquet topological system with ultracold atoms — •Christoph Braun[1,2,3], Raphaël Saint-Jalm[1,2], Alexander Hesse[1,2], Monika Aidelsburger[1,2], and Immanuel Bloch[1,2,3] — [1]Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Floquet engineering has proven as a powerful experimental tool for the realization of quantum systems with exotic properties. We study anomalous Floquet systems that exhibit robust chiral edge modes, despite all Chern numbers being equal to zero. The system consists of bosonic atoms in a periodically driven honeycomb lattice and we infer the topological invariants from measurements of the energy gap and local Hall deflections.

An interesting future direction is the interplay between topology and disorder in periodically-driven systems. In particular the existence of disorder-induced topological phases such as the anomalous Floquet Anderson insulator show the interesting link between topology and disorder.

Q 6.17 Tue 16:30 P

Self-organized topological insulator due to cavity-mediated correlated tunneling — Titas Chanda[1], •Rebecca Kraus[2], Giovanna Morigi[2], and Jakub Zakrzewski[1] — [1]Institute of Theoretical Physics, Jagiellonian University in Kraków, Kraków, Poland — [2]Theoretical Physics, Saarland University, Saarbrücken, Germany

Topological materials have potential applications for quantum technologies. Non-interacting topological materials, such as e.g., topological insulators and superconductors, are classified by means of fundamental symmetry classes. It is instead only partially understood how interactions affect topological properties. Here, we discuss a model where topology emerges from the quantum interference between single-particle dynamics and global interactions. The system is composed by soft-core bosons that interact via global correlated hopping in a one-dimensional lattice. The onset of quantum interference leads to spontaneous breaking of the lattice translational symmetry, the corresponding phase resembles nontrivial states of the celebrated Su-Schriefer-Heeger model. Like the fermionic Peierls instability, the emerging quantum phase is a topological insulator and is found at half fillings. Originating from quantum interference, this topological phase is found in "exact" density-matrix renormalization group calculations and is entirely absent in the mean-field approach. We argue that these dynamics can be realized in existing experimental platforms, such as cavity quantum electrodynamics setups, where the topological features can be revealed in the light emitted by the resonator.

Q 7: Precision Measurements

Time: Tuesday 16:30–18:30 Location: P

Q 7.1 Tue 16:30 P

Prototype of a compact rubidium-based optical frequency reference for operation on nanosatellites — •Aaron Strangfeld[1,2], Simon Kanthak[1,2], Max Schiemangk[2], Benjamin Wiegand[1], Andreas Wicht[2], Alexander Ling[3], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Deutschland — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Deutschland — [3]Centre for Quantum Technologies, National University of Singapore, Block S15, 3 Science Drive 2, Singapore 117543, Singapur

A compact laser system with integrated spectroscopy unit was developed as a prototype for optical frequency references on nanosatellites. Light from a distributed feedback laser diode is used for spectroscopy of rubidium in a vapor cell. The microintegration of optics with a size of a few millimeters allowed a significant size reduction ($70 \times 26 \times 19$ mm^3) while maintaining the performance of larger realizations: $\sigma_y(\tau = 1\text{s}) = 1.7 \times 10^{-12}$.

This work has been done in a joint collaboration between Humboldt-Universität zu Berlin and National University of Singapore, supported by the Berlin University Alliance and by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RK1971. The microintegration was realized at Ferdinand-Braun-Institut gGmbh, Leibniz-Institut für Höchstfrequenztechnik.

Q 7.2 Tue 16:30 P

Towards a strontium based Ramsey-Bordé optical frequency reference — •Oliver Fartmann[1], Conrad L. Zimmermann[1], Martin Jutisz[1], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We report on the status of our optical frequency reference based on Ramsey-Bordé interferometry. We utilize the $^1S_0 \rightarrow {}^3P_1$ intercombination line at 689 nm in a thermal atomic strontium beam.

We will give an overview on the system architecture and present first results of the compact high flux atomic oven, the cavity stabilized laser system as well as the atom interferometer package.

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 DLR50WM1852 and by the German Federal Ministry of Education and Research (BMBF) within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 7.3 Tue 16:30 P

Tandem Neural Network for Design of High-Reflectivity Metamirrors — •Liam Shelling Neto[1,3], Anastasiia Sorokina[1,3], Johannes Dickmann[1,3], Jan Meyer[1,3], Tim Käseberg[2], and Stefanie Kroker[2,3] — [1]Laboratory for Emerging Nanometrology (LENA), Technical University of Braunschweig, Langer Kamp 6a/b, 38106 Braunschweig — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [3]Cluster of Excellence QuantumFrontiers

In recent years, sub-wavelength structures that interact with light gained increasing attention thanks their ability to manipulate different aspects of the impinging electromagnetic wave, e.g. phase, amplitude or even polarization. The composition of such artificial structures pave the way for a multitude of applications such as ultrathin metalenses or hologram generation. In order to control the vast design space that unfolds with the desired flexibility of those nanostructures, many approaches have been reported in the past. Deep Learning efficiently tackles the problem of large parameter spaces since that is part of its intrinsic nature. In this Poster, we utilize a Tandem Neural Network to design focusing metamirrors with excellent phase agreement while maximizing reflectivity within a given design space.

Q 7.4 Tue 16:30 P

Test setup for cryogenic sensors and actuators working towards the Einstein Telescope — •Robert Joppe, Matthias Bovelett, Tim Kuhlbusch, Thomas Hebbeker, Vivek Pimpalshende, Oliver Pooth, Achim Stahl, Jan Wirtz, Franz-Peter Zantis, and Markus Bachlechner — RWTH Aachen, Aachen, Deutschland

The Einstein Telescope will be the first gravitational wave detector of the third generation. The sensitivity goal, especially in the low frequency region, will be achieved among other improvements by cooling the main parts of the interferometer. The required electronic components, sensors and actuators needed for mirror alignment and active dampening of suspension resonances have to perform at cryogenic temperatures.

In this poster we will present our work on electronics and mechanics within the E-TEST project. Furthermore the performance of our cryogenic UHV test setup will be explicated.

Q 7.5 Tue 16:30 P

Matter-Wave sensing for inertial navigation — •Mouine Abidi[1], Philipp Barbey[1], Vera Vollenkemper[1], Ashwin Rajagopalan[1], Yueyang Zou[1], Christian Schubert[1,2], Dennis Schlippert[1], Sven Abend[1], and Ernst.M Rasel[1] — [1]Institut für Quantenoptik - Leibniz Universität, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

Precise inertial navigation and positioning play a determining role in our daily life. Actual navigation systems cannot be used for certain fields since they suffer from device-dependent drifts, requiring GNSS correction that is not possible for example in buildings or space. Therefore, solutions based on a new technology had become a huge demand.

Quantum hybrid navigation combines conventional Inertial Measurement Units with quantum sensors based on atom interferometry. Atom interferometers have proven to measure drift-free at very high sensitivities. They can be used regardless of their small bandwidth and dynamic range to subtract the drifts of the classical devices.

This combination proposes a better performance and security for traditional navigation domains and an efficient tool to explore inertial measurement in new areas. We present the current status of our test stand for a quantum navigation system employed on a gyro-stabilized platform.

This work is supported by the Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under Grand No. DLR 50RK1957 (QGyro).

Q 7.6 Tue 16:30 P

A Quantum Optical Microphone in the Audio Band — •Raphael Nold[1], Charles Babin[1], Joel Schmidt[1], Tobias Linkewitz[1], Mária Pérez Zaballos[2], Rainer Stöhr[1], Roman Kolesov[1], Vadim Vorobev[1], Danil Lukin[3], Rüdiger Boppert[4], Stefanie Barz[1], Jelena Vuckovic[3], Christof Gebhardt[5], Florian Kaiser[1], and Jörg Wrachtrup[1] — [1]University of Stuttgart, Germany — [2]Cambridge University, UK — [3]Stanford University, USA — [4]Olgahospital Stuttgart, Germany — [5]Ulm University, Germany

The ability to perform high-precision optical measurements is paramount to science and engineering. Especially laser interferometry enables interaction-free sensing in which precision is ultimately limited by shot noise. Quantum optical enhanced sensors can surpass this limit. We introduce a novel cavity-free nonlinear interferometer that achieves sub-shot noise performance in continuous operation. We combine the advantages of low parametric gain operation and post selection free difference intensity detection with common mode noise cancellation. This allows us to measure phase-shifts more than four orders of magnitude faster compared to previous experiments based on photon number states. Further we present the implementation of a complex application as a quantum microphone in the audio band (frequency range $200 - 20,000\,\mathrm{Hz}$). Recordings of both, the quantum sensor and an equivalent classical counterpart are benchmarked with a medically-approved speech recognition test, which shows that the quantum sensor leads to a by 0.29 dB reduced speech recognition threshold. We thus make the quantum advantage audible to humans.

Q 7.7 Tue 16:30 P

Highly stable UV laser system for a transportable Al^+ quantum logic optical clock — •Benjamin Kraus[1,2], Stephan Hannig[1,2], Sofia Herbers[1,2], Dewni Pathegama[1], Fabian Dawel[1], Johannes Kramer[1], Constantin Nauk[1,2], Christian Lisdat[1], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany — [3]Leibniz Universität Hannover, 30167 Hannover, Germany

Optical atomic clocks provide the most precise frequency standards. They enable high accuracy tests of fundamental physics, relativistic geodesy, and a possible future redefinition of the SI second. For side-by-side clock comparisons, highly accurate transportable optical clocks are necessary. We report on our newly built clock laser system for a transportable Al^+ clock with its clock transition at 267.4 nm. The system consists of the laser source at 1069.6 nm, a highly stable optical reference cavity, a frequency quadrupling system, and the electronic control system all built in one rack. In particular we highlight the frequency quadrupling system consisting of two cascaded single-pass second harmonic generation(SHG) stages. The set-up is interferometrically phase-stabilized and built inside a hermetically sealed aluminium box to form a robust, compact, and stable fibre-coupled module. Additionally, a robust fibre-coupled single-pass acousto-optical modulator module at 267.4 nm for frequency shifting or switching the laser light is presented.

Q 7.8 Tue 16:30 P

Hybridizing an atom interferometer with an opto-mechanical resonator — •Ashwin Rajagopalan[1], Lee Kumanchik[2,3], Claus Braxmaier[2,3], Felipe Guzmán[4], Ernst M. Rasel[1], Sven Abend[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover — [2]DLR - Institute of Space Systems, Bremen — [3]University of Bremen - Center of Applied Space Technology and Microgravity (ZARM),Bremen — [4]Department of Aerospace Engineering & Physics, Texas A&M University, College Station, TX 77843, USA

With hybridization we have a quantum and classical sensor measuring acceleration with respect to a joint inertial reference therefore enabling common mode noise rejection. We have used a novel opto-mechanical resonator in order to suppress the effects of inertial noise coupling in our atom interferometer. The OMR possesses a very small form factor, therefore apart from eradicating the need to use a vibration isolation system it also allows for compact dimensions of the sensor head. Therefore, considering the complimentary benefits of the quantum sensor and OMR we foresee the potential for a highly sensitive, portable, compact and robust hybrid quantum inertial navigation sensor.

Reference: Richardson, L.L., Rajagopalan, A., Albers, H. et al. Optomechanical resonator-enhanced atom interferometry. Commun Phys 3, 208 (2020). https://doi.org/10.1038/s42005-020-00473-4

Q 7.9 Tue 16:30 P

An ultra-stable clock laser system for an Al^+ ion clock — •Dewni Pathegama[1], Sofia Herbers[1,2], Eileen Annika klocke[1,3], Stephan Hannig[1,2], Benjamin Kraus[1,2], Piet O. Schmidt[1,2,4], Uwe Sterr[1], and Christian Lisdat[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany — [3]currently with Askion GmbH, Gera, Germany — [4]Leibniz University of Hannover, Hannover, Germany

Transportable optical clocks are increasingly used in applications like relativistic geodesy. One of the key components of an optical clock is an ultra-stable interrogation laser, whose instability affects the clock performance via the Dick effect.

Here we present a clock laser system designed for a transportable Al^+ clock [Hannig et al., Rev. Sci. Instrum. **90**, 053204 (2019)]. The system consists of a DFB fiber laser locked to a cavity with crystalline mirror coatings [Cole et al., Nat. Phot. **7**, 644 (2013)] to reduce the thermal noise contribution of the cavity below 10^{-16} fractional frequency instability. Additionally, suppression of residual amplitude modulation (RAM), power stabilization of the light oscillating in the cavity, and temperature stabilization of the cavity will be employed to reach an instability as low as 10^{-16}. The laser is operated at 1069.6 nm, and fourth harmonic generation is implemented to reach the 267.4 nm interrogation wavelength of Al^+. All the components including the cavity and electronics are designed to be installed inside a single rack.

Q 7.10 Tue 16:30 P

Characterizing the sensitivity levels of a shadow sensor - working towards a cryo-compatible sensor — •Vivek Pimpalshende, Markus Bachlechner, Matthias Bovelett, Thomas Hebbeker, Robert Joppe, Tim Kuhlbusch, Oliver Pooth, Achim Stahl, Jan Wirtz, and Franz-Peter Zantis — RWTH Aachen University, Aachen, Germany

The Einstein Telescope will be the first gravitational wave detector of the third generation. The sensitivity goal, especially in the low-frequency region, will be achieved among other improvements by cooling the main parts of the interferometer. Thus, the required electronic components, sensors, and actuators needed for mirror alignment and active damping of suspension resonances have to perform at cryogenic temperatures. In a shadow sensor, the displacement of a flag is measured from its shadow cast onto a photodiode. In this poster, we will present our work on the characterization of the noise level of a shadow sensor. Understanding the noise sources is crucial to improve the sensitivity, which is essential to design an efficient cryo-compatible sensor.

Q 7.11 Tue 16:30 P

Frequency stability of a cryogenic silicon resonator with crystalline mirror coatings — •Jialiang Yu[1], Thomas Legero[1], Fritz Riehle[1], Daniele Nicolodi[1], Dhruv Kedar[2], John Robinson[2], Eric Oelker[3], Jun Ye[2], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado, USA — [3]University of Glasgow, UK

The performance of ultra-stable lasers is ultimately limited by various types of thermal noise, with Brownian thermal noise of the optical coatings as the largest contribution.

We have set up a 21 cm long optical resonator made from single-crystal silicon with $Al_{0.92}Ga_{0.08}As$/GaAs crystalline mirror coatings, which is operated at a cryogenic temperature of 124 K. Compared to usual dielectric coatings, the crystalline coatings are expected to have a lower mechanical loss, thus improving the frequency stability to 1×10^{-17}. The most important technical noise sources affecting the frequency stability are suppressed to a level below this predicted thermal noise floor for averaging times between 5 s and 1000 s. However, the lowest measured frequency instability of 4.5×10^{-17} is significantly higher than predicted. Compared to dielectric coatings we observe a much more complex behavior of the crystalline semiconductor coatings on e.g. fluctuations of the intracavity power. The influence on cavity frequency stability is investigated by locking simultaneously two lasers to different cavity modes.

Q 7.12 Tue 16:30 P

A laser system for combining Bragg and Raman processes — •Ekim T. Hanimeli[1], Martina Gebbe[1], Matthias Gersemann[2], Simon Kanthak[3,4], Sven Abend[2], Sven Herrmann[1], Claus Lämmerzahl[1], and QUANTUS team[1,2,3,4] — [1]ZARM, Universität Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Ferdinand-Braun-Institut, Berlin

Bragg and Raman diffractions are commonly used in atom interferometry to form beam splitters and mirrors. The two processes differ in their internal state transitions, so their combination enables the creation of novel interferometry topologies through the inclusion of both internal and external states. Here, we present the new fibre-optical laser system capable of implementing both Bragg and Raman processes as well as double diffractions, allowing a wide variety of possibilities to be achieved. Especially for Raman diffraction a low-phase noise implementation for the hyperfine splitting is mandatory. In our system this is realized with a combination of an electro-optical modulator and a fibre Bragg grating, which suppresses the unwanted optical sidebands in the modulation.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under Grant No. 50WM1952 (QUANTUS-V-Fallturm).

Q 7.13 Tue 16:30 P

Analytic Theory for Diffraction Phases in Bragg Interferometry — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], 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

High-fidelity Bragg pulses operate in the quasi-Bragg regime. While such pulses enable an efficient population transfer essential for state-of-the-art atom interferometers, the diffraction phase and its dependence on the pulse parameters are currently not well characterized despite playing a key role in the systematics of these interferometers. We demonstrate that the diffraction phase when measuring relative atom numbers originates from the fact that quasi-Bragg beam splitters and mirrors are fundamentally multi-port operations governed by Landau-Zener physics (Siemß et al., Phys. Rev. A 102, 033709).

We develop a multi-port scattering matrix representation of the popular Mach-Zehnder atom interferometer and discuss the connection between its phase estimation properties and the parameters of the Bragg pulses. Furthermore, our model includes the effects of linear Doppler shifts applicable to narrow atomic velocity distributions on the scale of the photon recoil of the optical lattice.

This work is supported through the Deutsche Forschungsgemeinschaft (DFG) under EXC 2123 QuantumFrontiers, Project-ID 390837967 and under the CRC1227 within Project No. A05 as well as by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 7.14 Tue 16:30 P

Measuring Gravity with Very Long Baseline Atom Interferometry — •Ali Lezeik, Klaus Zipfel, Dorothee Tell, Christian Meiner, Chrisitan Schubert, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover- Insititute für Quantenoptik, Germany

Matter-wave interferometers with ultracold atoms are highly sensitive to inertial quantities. The Very Long Baseline Atom Interferometry (VLBAI) facility at the Hannover Institute of Technology (HiTech) aims to exploit the linear scaling of this sensitivity with the free fall time of the atoms in a 10 m baseline [1]. This will enable precision measurements of gravitational acceleration, as well as tests of the weak equivalence principle and gravitational redshift [2,3].

We present the current status of the VLBAI, the 20cm diameter vacuum chamber with the high performance magnetic shield that achieved residual fields below 4 nT and longitudinal inhomogeneities below 2.5 nT/m over 8 m along the longitudinal direction. We additionally report on the source of laser-cooled ytterbium atoms delivering 1×10^9 atoms/s in a 3D magneto-optical trap. With such upgrades, tests of the universality of free fall with atomic test masses beyond the 10^{-13} level can be achieved.

[1] J. Hartwig et al., New J. Phys. 17 (2015)
[2] D. Schlippert et al., arXiv:1909.08524 (2019)
[3] S. Loriani et al., Sci. Adv. 5 (2019)

Q 8: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Tuesday 16:30–18:30 Location: P

Q 8.1 Tue 16:30 P

Ultrafast Electron Cooling in an Ultracold Microplasma — •Mario Grossmann, Tobias Kroker, Julian Fiedler, Jette Heyer, Markus Drescher, Klaus Sengstock, Philipp Wessels-Staarmann, and Juliette Simonet — The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg

We utilize the strong light-field of a focused femtosecond laser pulse to instantaneously and locally ionize a controlled number of atoms within a ^{87}Rb Bose-Einstein condensate.
The large atomic densities above 10^{20} m^{-3} combined with low ion temperatures below 40 mK give rise to an initially strongly coupled plasma with up to a few thousand electrons and ions.
Our experimental setup allows us to tune the density, volume and number of ionized atoms as well as the excess energy after ionization which sets the neutrality of the ultracold plasma.
By directly measuring the kinetic energy of the emerging electrons from a highly charged plasma we observe a cooling of the electronic component from 5250 K to 10 K in less then 500 ns.
The finite particle number permits us to perform exact numerical calculations of the plasma dynamics with long-range Coulomb interactions in excellent agreement with our experimental data. These simulations reveal the picosecond dynamics of each particle as well as the ultrafast energy transfer between the electronic and ionic components of the plasma, bridging the natural time-scales of ultracold neutral plasma and ionized nanoclusters.

Q 8.2 Tue 16:30 P

Quantum sensing protocol for motionally chiral Rydberg atoms — Stefan Yoshi Buhmann[1], Steffen Giesen[2], Mira Diekmann[2], Robert Berger[2], •Stefan Aull[3], Markus Debatin[3], Peter Zahariev[3,4], and Kilian Singer[3] — [1]Theoretische Physik III, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Fachbereich Chemie, Philipps-Universität Marburg, Hans-Meerwein-Str 4, Marburg 35032, Germany — [3]Experimentalphysik I, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [4]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

A quantum sensing protocol is proposed for demonstrating the motion-induced chirality of circularly polarised Rydberg atoms. To this end, a cloud of Rydberg atoms is dressed by a bichromatic light field. This allows to exploit the long-lived ground states for implementing a Ramsey interferometer in conjunction with a spin echo pulse sequence for refocussing achiral interactions. Optimal parameters for the dressing lasers are identified. Combining a circularly polarised dipole transition in the Rydberg atom with atomic centre-of-mass motion, the system becomes chiral. The resulting discriminatory chiral energy shifts induced by a chiral mirror are estimated using a macroscopic quantum electrodynamics approach.

Q 8.3 Tue 16:30 P

Reconstructing three-dimensional density distributions from absorption images — Henrik Zahn[1], •Maximilian Klaus Müllenbach[2], Titus Franz[2], Clément Hainaut[2], Gerhard Zürn[2], and Matthias Weidemüller[2] — [1]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

We present a novel method to reconstruct a three-dimensional density distribution from its two-dimensional projection in a suitably chosen direction as long as the distribution has an a-priori known continuous symmetry. Our method extends the well-known Abel transform for distributions with axial or spherical symmetry to distributions with more general continuous symmetries. A-priori knowledge of the present symmetries allows us to solve the inversion problem by finding the density distribution's values along its isolines. We apply our method to two distinct settings, the first one being such that Abel inversion can be applied, i.e. rotational symmetry about an axis perpendicular to the integration direction. In the second setting we apply our method to study excitation dynamics of Rydberg atoms, featuring a complex symmetry determined by the cigar-like shape of the ground state density distribution and the axially symmetric excitation laser, angled at 45° with respect to the ground state symmetry axis.

Q 8.4 Tue 16:30 P

Towards an optogalvanic flux sensor for nitric oxide based on Rydberg excitations — Patrick Kaspar[1,5], Fabian Munkes[1,5], •Yannick Schellander[3], Lars Baumgärtner[2], Lea Ebel[1], Denis Djekic[2], Patrick Schalberger[3], Holger Baur[3], Jens Anders[2,5], Edward Grant[4], Norbert Frühauf[3], Robert Löw[1,5], Tilman Pfau[1,5], and Harald Kübler[1,5] — [1]5 Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Institut für Intelligente Sensorik und Theoretische Elektrotechnik, Universität Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart — [3]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Allmandring 3b, 70569 Stuttgart — [4]Department of Chemistry & Department of Astronomy, The University of British Columbia, 2036 Main Mall, Vancouver, BC Canada V6T 1Z1 Vancouver, Canada — [5]Center for Integrated Quantum Science and Technology, Universität Stuttgart

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 electrons can be measured as a current. In a proof of concept experiment a detection limit of 10 ppm in a background of He was demonstrated [1,2]. We show first results of the continous wave sensor prototype and first signals of Doppler-free laser spectroscopy on nitric oxide.

[1] J. Schmidt, et. al., *Appl. Phys. Lett.* **113**, 011113 (2018)
[2] J. Schmidt, et. al., SPIE **10674** (2018)

Q 8.5 Tue 16:30 P

Two-dimensional spectroscopy of Rydberg gases — •Kaustav Mukherjee[1], Himangshu Prabal Goswami[2,4], Shannon Whitlock[3], Sebastian Wüster[1], and Alexander Eisfeld[4] — [1]Indian Institute of Science Education and Research, Bhopal, India — [2]Gauhati University, Guwahati, India — [3]University of Strasbourg and CNRS, Strasbourg, France — [4]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Two-dimensional (2D) spectroscopy uses multiple electromagnetic pulses to infer the properties of a complex system. A paradigmatic class of target systems is molecular aggregates, for which one can obtain information on the eigenstates, various types of static and dynamic disorder, and relaxation processes. However, two-dimensional spectra can be difficult to interpret without precise knowledge of how the signal components relate to microscopic Hamiltonian parameters and system-bath interactions. Here we show that two-dimensional spectroscopy can be mapped in the microwave domain to highly controllable Rydberg quantum simulators. By porting 2D spectroscopy to Rydberg atoms, we firstly open the possibility of its experimental quantum simulation, in a case where parameters and interactions are very well known. Secondly, the technique may provide additional handles for experimental access to coherences between system states and the ability to discriminate different types of decoherence mechanisms in Rydberg gases. We investigate the requirements for a specific implementation utilizing multiple phase-coherent microwave pulses and a phase cycling technique to isolate signal components.

Q 9: Quantum Gases

Time: Wednesday 10:45–12:15 Location: H2

Invited Talk Q 9.1 Wed 10:45 H2

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.

Invited Talk Q 9.2 Wed 11:15 H2

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 intriguing phenomena such as pseudogap physics and high temperature superfluidity. Their central features, such as fermion pairing and collective excitations, can approximately be understood in the many-particle limit. It is an open question how large a system has to be for such a many-body picture to apply.

I will report on experiments that realize microscopic two-dimensional systems with ultracold fermionic lithium. With the ability to deterministically prepare few-body ground states and to observe individual atoms in momentum space, they enable a microscopic view of strongly interacting two-dimensional Fermi systems.

Surprisingly, we find that characteristic features of many-body Fermi gases can already be found in systems of no more than a dozen particles: In spectroscopy, we observe collective excitations that are the few-body precursor of the Higgs amplitude mode of a superfluid. Moreover, in spin-resolved momentum space probes, we can directly image individual 'Cooper pairs' and show the presence of fermionic pairing even in a microscopic setting. These findings confirm our qualitative picture of fermionic pairing in two dimensions and may be compared to other finite-size Fermi systems, such as atomic nuclei and superconducting grains.

Invited Talk Q 9.3 Wed 11:45 H2

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 10: Precision spectroscopy of atoms and ions / Highly charge ions (joint session A/Q)

Time: Wednesday 14:00–16:00 Location: H1

Invited Talk Q 10.1 Wed 14:00 H1

Laser spectroscopy of the heaviest actinides — •Premaditya Chhetri[1,2,3], Dieter Ackermann[4], Hartmut Backe[5], Michael Block[1,2,5], Bradley Cheal[6], Christoph Emanuel Düllmann[1,2,5], Julia Even[7], Rafael Ferrer[3], Francesca Giacoppo[1,2], Stefan Götz[1,2,5], Fritz Peter Hessberger[1,2], Mark Huyse[3], Oliver Kaleja[1,5], Jadambaa Khuyagbaatar[1,2], Peter Kunz[8], Mustapha Laatiaoui[1,2,5], Werner Lauth[5], Lotte Lens[1], Enrique Minaya Ramirez[9], Andrew Mistry[1,2], Tobias Murböck[1], Sebastian Raeder[1,2], Fabian Schnieder[2], Piet Van Duppen[3], Thomas Walther[10], and Alexander Yakushev[1,2] — [1]GSI, Darmstadt, Germany — [2]HI Mainz, Mainz, Germany — [3]KU Leuven, Leuven, Belgium — [4]GANIL, Cean, France — [5]JGU, Mainz, Germany — [6]Liverpool University, Liverpool, UK — [7]University of Groningen, KVI-CART, Groningen, Netherlands — [8]TRIUMF, Vancouver, Canada — [9]IPN, Orsay, France — [10]TU Darmstadt, Darmstadt, Germany

Precision measurements of optical transitions of the heaviest elements are a versatile tool to probe the electronic shell structure which is strongly influenced by electron-electron correlations, relativity and QED effects. Optical studies of transfermium elements with Z>100 is hampered by low production rates and the fact that any atomic information is initially available only from theoretical predictions. Using the sensitive RAdiation Detected Resonance Ionization Spectroscopy (RADRIS) technique coupled to the SHIP separator at GSI, a strong optical $^1S_0 \rightarrow {}^1P_1$ ground-state transition in the element nobelium (Z=102) was identified and characterized [1]. The isotopes of ^{252,253,254}No were measured [2]. From these measurements, nuclear information on the shapes and sizes were inferred. In addition, several high-lying Rydberg levels were observed, which enabled the extraction of the first ionization potential with high precision [3]. Using an indirect production mechanism, laser spectroscopy was performed on some Fermium isotopes. These results as well as the prospects for future exploration of the atomic structure of the next heavier element, lawrencium (Z=103) will be discussed.

[1] M. Laatiaoui et al., Nature **538**, 495 (2016).
[2] S. Raeder et al., PRL **120**, 232503 (2018).
[3] P. Chhetri et al., PRL **120**, 263003 (2018).

Invited Talk Q 10.2 Wed 14:30 H1

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)

Invited Talk Q 10.3 Wed 15:00 H1

Coupled ions in a Penning trap for ultra-precise *g*-factor differences — •Tim Sailer[1], Vincent Debierre[1], Zoltán Harman[1], Fabian Heisse[1], Charlotte König[1], Jonathan Morgner[1], Bingsheng Tu[1], Andrey Volotka[2], Christoph H. Keitel[1], Klaus Blaum[1], and Sven Sturm[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Department of Physics and Engineering, ITMO University, St. Petersburg, Russia

Measurements of the electronic magnetic moment (or g factor) of highly charged ions (HCI) in Penning traps have been shown to provide a stringent probe for quantum electrodynamics (QED) in the strongest electromagnetic fields. The isotope shift additionally allows the study of nuclear parameters since many of the common contributions and their uncertainties to the g factor are identical and do not have to be considered. Such measurements become however quickly limited by other factors, for example inherent magnetic field fluctuations. Here, we report on a novel measurement technique based on coupling two ions on a common magnetron orbit to exploit the near-perfect correlation of such magnetic field fluctuations. This has enabled us to directly measure the difference for the isotopes of $^{20}Ne^{9+}$ and $^{22}Ne^{9+}$ to 0.25 parts-per-trillion precision relative to the g factors, which corresponds to an improvement of more than two orders of magnitude compared to conventional techniques. This resolves and verifies a QED contribution to the nuclear recoil for the very first time, while the observed agreement with theory also allows to strengthen the constraints for a potential fifth-force of Higgs-portal-type dark matter interaction.

Invited Talk Q 10.4 Wed 15:30 H1

Unraveling the mechanisms of single- and multiple-electron removal in energetic electron-ion collisions: from few-electron ions to extreme atomic systems. — •Alexander Borovik Jr — I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Giessen, Germany

For over a half century, electron-impact ionization of ions remains an open topic in atomic physics [1]. While single-electron removal processes in light few-electron systems are currently understood and can be reliably described by theoretical approaches, ionization of many-electron ions, especially multiple ionization, are still not understood completely. In this situation, experiment, where available, is the only reliable source of information [2]. However, as we move to ions in high charge states, requirements on the experimental conditions rise, making new approaches and instrumentation necessary. In the present overview, we describe the current status in the field and report on recent activities that aim at expanding the experimental capabilities by the development of electron guns beyond the state-of-the-art and by employing large heavy-ion accelerator facilities such as FAIR [3].

[1] A. Müller, Adv. At. Mol. Phys. 55, 293 (2008). [2] D. Schury et al. J. Phys. B 53, 015201 (2019). [3] M. Lestinsky et al., Eur. Phys. J. ST 225, 797882 (2016).

Q 11: Quantum Information (joint session QI/Q)

Time: Wednesday 16:30–18:30 Location: P

Q 11.1 Wed 16:30 P

Does a disordered isolated Heisenberg spin system thermalize? — •Titus Franz[1], Adrien Signoles[2], Renato Ferracini Alves[1], Clément Hainaut[1], Sebastian Geier[1], Andre Salzinger[1], Annika Tebben[1], Shannon Whitlock[3], Gerhard Zürn[1], Martin Gärttner[4], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg, Germany — [2]Pasqal, 91120 Palaiseau, France — [3]IPCMS and ISIS, University of Strasbourg and CNRS, 67000 Strasbourg, France — [4]Kirchhoff-Institut für Physik, Universität Heidelberg, 69120 Heidelberg, Germany

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 seem to disagree with Eigenstate Thermalization Hypothesis (ETH), which indicates that either a better theoretical understanding of thermalization is required or ETH breaks for the here studied quench in a disordered spin system.

Q 11.2 Wed 16:30 P

How Quantum Evolution with Memory is Generated in a Time-Local Way — •Konstantin Nestmann[1,2], Valentin Bruch[1,2], and Maarten R. Wegewijs[1,2,3] — [1]RWTH Aachen — [2]JARA-FIT — [3]Peter Grünberg Institut

Two widely used approaches to the dynamics of open quantum systems with strong dissipation and memory are the Nakajima-Zwanzig and the time-convolutionless quantum master equation. The first one uses a *time-nonlocal* memory kernel $\mathcal{K}$, whereas the second achieves the same using a *time-local* generator $\mathcal{G}$. Here we show that the two are connected by a simple yet general fixed-point relation: $\mathcal{G} = \hat{\mathcal{K}}[\mathcal{G}]$ [1].

This result provides a deep connection between these two entirely different approaches with applications to strongly interacting open quantum systems [2]. In particular, it explicitly relates two widely used but *distinct* perturbative expansions [3], quantitatively connects the *distinct* non-perturbative Markov approximations they define, and resolves the puzzling issue how these manage to converge to exactly the same stationary state.

Furthermore, our fixed-point equation naturally leads to an iterative procedure to compute the time-local generator directly from the memory kernel producing non-Markovian approximations which are guaranteed to be accurate both at short and long times.

[1] Phys. Rev. X **11**, 021041 (2021)
[2] arXiv:2104.11202
[3] arXiv:2107.08949

Q 11.3 Wed 16:30 P

Tailored Optical Clock Transition in $^{40}Ca^{+}$ — •Lennart Pelzer[1], Kai Dietze[1], Johannes Kramer[1], Fabian Dawel[1], Ludwig Krinner[1,2], Nicolas Spethman[1], Victor Martinez[2], Nati Aharon[3], Alex Retzker[3], Klemens Hammerer[2], and Piet Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, — [3]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

Optical clocks based on single trapped ions are often impeded by long averaging times due to the quantum projection noise limit. Longer probe time would improve the statistical uncertainty, but currently, phase coherence of clock laser systems is limiting probe times for most clock candidates. We propose pre-stabilization of the laser to a larger $^{40}Ca^{+}$ ion crystal, offering a higher signal-to-noise ratio. We engineer an artificial optical clock transition with a two stage continuous dynamical decoupling scheme, by applying near-resonant rf dressing fields. The scheme suppresses inhomogeneous tensor shifts as well as the linear Zeeman shift, making it suitable for multi-ion operation. This tailored transition has drastically reduced magnetic-field sensitivity. Even without any active or passive magnet-field stabilization, it can be probed close to the second-long natural lifetime limit of the $D_{5/2}$ level. This ensures low statistical uncertainty. In addition, we show a significant suppression of the quadrupole shift on a linear five-ion crystal by applying magic angle detuning on the rf-drives.

Q 11.4 Wed 16:30 P

Experimental exploration of fragmented models and non-ergodicity in tilted Fermi-Hubbard chains — •Clara Bachorz[1], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Pablo Sala[3], Frank Pollmann[3], Bharath Hebbe Madhusudhana[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]LMU Munich, Germany — [2]Max-Planck institut fur Quantenoptik, Garching, Germany — [3]TUM Munich, Germany

Thermalization of isolated quantum many-body systems is deeply related to redistribution of quantum information in the system. A question of fundamental importance is when do quantum many-body systems fail to thermalize, i.e., feature non-ergodicity. A test-bed for the study of non-ergodicity is the tilted Fermi-Hubbard model, which is directly accessible in experiments with ultracold atoms in optical lattices. Here we experimentally study non-ergodic behavior in this model by tracking the evolution of an initial charge-density wave [1]. In the limit of large tilts, we identify the microscopic processes which the observed dynamics arise from. These processes constitute an effective Hamiltonian and we experimentally show its validity [2]. This effective Hamiltonian features the novel phenomenon of Hilbert space fragmentation. For intermediate tilts, while these effective models are no longer valid, we show that the features of fragmentation are still vaguely present in the dynamics. Finally, we explore the relaxation dynamics of the imbalance in a 2D tilted Fermi-Hubbard system.

[1.] Sebastian Scherg et al. arXiv:2010.12965
[2.] Thomas Kohlert et al. arXiv:2106.15586

Q 11.5 Wed 16:30 P

Quantifying necessary quantum resources for nonlocality — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Nonlocality is one of the most important resources for quantum information protocols. The observation of nonlocal correlations in a Bell experiment is the result of appropriately chosen measurements and quantum states. We study quantitatively which quantum resources within the state and measurements are needed to achieve a given degree of nonlocality by exploiting the hierarchical structure of the resources. More explicitly, we quantify the minimal purity to achieve a certain Bell value for any Bell operator. Since purity is the most fundamental resource of a quantum state, this enables us also to quantify the necessary coherence, discord, and entanglement for a given violation of two-qubit correlation inequalities. Our results shine new light on the CHSH inequality by showing that for a fixed Bell violation an increase in the measurement resources does not always lead to a decrease of the minimal state resources.

Q 11.6 Wed 16:30 P

Floquet Hamiltonian Engineering of an Isolated Many-Body Spin System — •Sebastian Geier[1], Nithiwadee Thaicharoen[1,2], Clément Hainaut[1], Titus Franz[1], Andre Salzinger[1], Annika Tebben[1], David Grimshandl[1], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Research Center for Quantum Technology, Faculty of Science, Chiang Mai University 239 Huay Kaew Road, Muang, Chiang Mai, 50200, Thailand

Controlling interactions is the key element for quantum engineering of many-body systems. Using time-periodic driving, a naturally given many-body Hamiltonian of a closed quantum system can be transformed into an effective target Hamiltonian exhibiting vastly different dynamics. We demonstrate such Floquet engineering with a system of spins represented by Rydberg states in an ultracold atomic gas. Applying a sequence of spin manipulations, we change the symmetry properties of the effective Heisenberg XYZ Hamiltonian. As a consequence, the relaxation behavior of the total spin is drastically modified. The observed dynamics can be qualitatively captured by a semi-classical simulation. Synthesising a wide range of Hamiltonians opens vast opportunities for implementing quantum simulation of non-equilibrium dynamics in a single experimental setting.

Q 11.7 Wed 16:30 P

Detecting Genuine Multipartite Entanglement Using Quantum Teleportation — •Sophie Egelhaaf, Harry Giles, and Paul Skrzypczyk — University of Bristol, Bristol, UK

In the standard quantum teleportation protocol one party is given an unknown quantum state that is teleported to another party, using a shared entangled state, a Bell state measurement and classical communication. In this work, we consider adding a third party, whose role is to act as a 'gatekeeper', either allowing or blocking the teleportation between the other two parties.

We show that the capabilities of the gatekeeper depend upon the type of multipartite entanglement they share with the other two parties. In particular, we show that a sufficiently ideal performance can only be achieved if the shared state is genuine multipartite entangled.

Q 11.8 Wed 16:30 P

Coupling Erbium Dopants to Silicon Nanophotonic Structures — Andreas Gritsch[1], Lorenz Weiss[1], •Johannes Früh[1], Stephan Rinner[1], Florian Burger[1], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität, München, Germany

Erbium dopants are promising candidates for the implementation of large-scale quantum networks since they can combine second-long ground state coherence with coherent optical transitions at telecommunication wavelength. Among the potential host crystals for erbium, silicon stands out because it allows for the scalable fabrication of nanophotonic devices based on established processes of the semiconductor industry. In contrast to observations of previous studies, we have shown that erbium ions implanted into silicon nanostructures can be integrated at well-defined lattice sites with narrow inhomogeneous (~1 GHz) and homogeneous (<0.1 GHz) linewidths [1]. By optimizing the sample preparation, we have recently improved the homogeneous linewidth down to 20 kHz. As the long lifetime of the optically excited state (~0.25 ms) would limit the achievable rates, we designed and fabricated photonic crystal cavities which may reduce the lifetime by more than three orders of magnitude. This will allow us to control individual dopants, making our system a promising candidate for the implementation of distributed quantum information processing.

[1] L. Weiss, A. Gritsch, B. Merkel, and A. Reiserer, Optica, 8, 40-41(2021)

Q 11.9 Wed 16:30 P

Site-specific Rydberg excitation in a multi-site quantum register of neutral atoms — •Tobias Schreiber, Dominik Schäffner, Jan Lautenschläger, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Applications in quantum technologies, such as quantum information science and metrology, demand for scalable platforms of identical quantum systems. Additionally, precise spatial control and fast switching of quantum states and of qubit coupling constitute milestones for quantum computing and simulation.

We present a micro-optical platform for defect-free assembled 2D clusters of more than 100 single-atom quantum systems [1] and demonstrate site-resolved excitations into various Rydberg states [2]. Together with fast addressing of individual array sites at a microsecond timescale, we gain real-time control over interactions between next neighbors in the quantum register. This allows the demonstration of Rydberg blockade with tunable blockade strength dependent on the respective state and atom separation. In combination with long coherence times for the prepared hyperfine states of the atoms, this technique leads the way to quantum computing and simulation with neutral atoms in our experimental setup.

[1] D. Ohl de Mello et. al., Phys. Rev. Lett. **122**, 203601 (2019).
[2] M. Schlosser et. al., J. Phys. B: At. Mol. Opt. Phys. **53** 144001 (2020).

Q 11.10 Wed 16:30 P

Characterising which causal structures might not support a classical explanation based on any underlying physical theory — •Shashaank Khanna and Matthew Pusey — Department of Mathematics, University of York, Heslington, UK

A causal relationship can be described using the formalism of Generalised Bayesian Networks. This framework allows the depiction of cause and effect relations (causal scenarios) effectively using generalised directed acyclic graphs (GDAGs). A GDAG is "not interesting" if the causal relations existing can be explained classically regardless of the underlying physical theory. Henson, Lal and Pusey (HLP) have proposed a sufficient condition to check whether a causal scenario is "not interesting". With their methods and some more developments the problem of identifying "interesting" causal structures has been solved for GDAGs of 6 nodes. But the problem of identifying "interesting" causal scenarios for GDAGs of 7 nodes is still open. We propose a new graphical theorem (and call it the E-separation theorem) to check several of the GADGs of 7 nodes which couldn't be checked by HLP's condition. Finally we also use "fine-grained" entropic inequalities to check whether the remaining GDAGs (of 7 nodes) are interesting or not.

Q 11.11 Wed 16:30 P

Average waiting times for entanglement links in quantum networks — •Lisa Weinbrenner, Lina Vandré, and Otfried Gühne — Universität Siegen, Deutschland

In quantum communication protocols using noisy channels the error probability typically scales exponentially with the length of the channel. To reach long-distance entanglement distribution, one can use quantum repeaters. These schemes involve first a generation of elementary bipartite entanglement links between two nodes and then measurements to join the elementary links. Since the generation of an elementary link is probabilistic and quantum memories have a limited storage time, the generation of a long-distance entangled link is probabilistic, too [1].

While the average waiting time for the generation of such a link in the case of just two elementary links is well understood [2], there is no analytical expression known for more than two links. The aim of this contribution is to explore estimations on the average waiting time for a long-distance entangled link for arbitrary network sizes.

[1] S. Khatri et al., Phys. Rev. Research 1, 023032 (2019)
[2] O. A. Collins et al., Phys. Rev. Lett 98, 060502 (2007)

Q 11.12 Wed 16:30 P

A perceptron quantum gate for quantum machine learning — •Patrick Huber[1], Erik Torrontegui[2], Johann Haber[3], Patrick Barthel[1], Juan Jose Garcia Ripoll[2], and Christof Wunderlich[1,3] — [1]Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen — [2]Instituto de Física Fundamental IFF-CSIC - Calle Serrano 113b, 28006 Madrid, Spain — [3]eleQtron GmbH, Martinshardt 19, 57074 Siegen

As quantum computing advances towards the implementation of noisy intermediate-scale quantum computers (NISQs), the number of applications and scientific use cases keep growing. A recent addition is machine learning. We demonstrate the implementation of a perceptron on an ion-based quantum computer comprised of three qubits, a bias qubit, a control qubit, and a target qubit, the latter of which encodes the output state of the perceptron. The system uses magnetic gradient induced coupling (MAGIC) which allows for the control of the qubits by microwave radiation. The magnetic gradient also induces an Ising-like interaction between individual ions. This property is exploited in order to implement the perceptron. We demonstrate both the working of the basic perceptron quantum gate as predicted in [1], and show that by successive application of the perceptron more sophisticated multi-qubit quantum gates can be implemented easily and straightforwardly.

[1] Unitary quantum perceptron as efficient universal approximator, E. Torrontegui and J. J. García-Ripoll EPL, 125 3 (2019) 30004 DOI: https://doi.org/10.1209/0295-5075/125/30004

Q 11.13 Wed 16:30 P

Spatial entanglement dynamics between two quantum walkers with symmetric and anti-symmetric coins — •Ibrahim Yahaya Muhammad[1], Tanapat Deesuwan[1], Sikarin Yoo-Kong[2], Suwat Tangwancharoen[1], and Monsit Tanasittikosol[1] — [1]Department of Physics, Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok, Thailand — [2]The Institute for Fundamental Study (IF), Naresuan University, Phitsanulok, Thailand

We investigate the dynamics of the spatial entanglement between two initially independent walkers that individually and identically perform discrete-time quantum walk with symmetric and anti-symmetric initial coin states. The numerical results show that the spatial entanglement between the two walkers behaves similarly to the dynamics of an underdamped oscillator. By considering the symmetry associated with the setting and post-selecting the states of the two coins accordingly, we show both numerically and analytically that, for the anti-symmetric initial coin state, the entanglement dynamics corresponding to all the "triplet" results are constant, and the damping behaviour only shows up in the "singlet" result. On the other hand, for the symmetric initial coin state, the relationships between the entanglement dynamics and the post-selecting results are the other way around. Moreover, we obtain the relationship between the period of oscillation (T) and the coin operator parameter (θ) for the damping case as $T = \pi/\theta$. Our findings reveal some interesting aspects of symmetry and quantum walks, which may be useful for applications in quantum communication and other quantum technology.

Q 11.14 Wed 16:30 P

Vibrationally-decoupled cryogenic surface-electrode ion trap for scalable quantum computing and simulation — •Niklas Orlowski[1], Timko Dubielzig[1], Sebastian Halama[1], Chloe Allen-Ede[1], Niels Kurz[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We present an overview of the necessary experimental infrastructure to perform experiments with an integrated microwave near-field surface-electrode ion trap at cryogenic temperatures for quantum logic applications [1]. We describe the measures to isolate the ions from environmental influences, like vibrational decoupling and XUHV-conditions. We discuss the loading scheme involving lasers for ablation and ionization as well as Doppler cooling, repumping and detection of $^9Be^+$-ions. State preparation and manipulation procedures with precisely timed and tuned microwave and laser pulses are presented. Finally, we report on thermal stabilization as required for reproducible radial sideband spectroscopy. The achieved stability of the radial sideband modes will allow for implementation of microwave sideband-cooling and microwave quantum gates [2].

[1] Dubielzig et al. RSI **92.4** (2021): 043201
[2] Zarantonello et al. PRL **123**, 260503

Q 11.15 Wed 16:30 P

Retrieval of single photons from solid-state quantum transducers — •Tom Schmit[1], Luigi Giannelli[1,2,3], Anders S. Sørensen[4], and Giovanna Morigi[1] — [1]Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbr+cken, Germany — [2]Dipartimento di Fisica e Astronomia "Ettore Majorana", Universit\a di Catania, Via S. Sofia 64, 95123 Catania, Italy — [3]INFN, Sez. Catania, 95123 Catania, Italy — [4]enter for Hybrid Quantum Networks (Hy-Q), Niels Bohr Institute,University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark

Quantum networks using photonic channels require control of the interactions between the photons, carrying the information, and the elements comprising the nodes. In this work, we theoretically analyse the spectral properties of an optical photon emitted by a solid-state quantum memory, which acts as a converter of a photon absorbed in another frequency range. We determine explicitly the expression connecting the stored and retrieved excitation taking into account possible mode and phase mismatching of the experimental setup. The expression we obtain describes the output field as a function of the input field for a transducer working over a wide range of frequencies, from optical-to-optical to microwave-to-optical. We apply this result to analyse the photon spectrum and the retrieval probability as a function of the optical depth for microwave-to-optical transduction. In the absence of losses, the efficiency of the solid-state quantum transducer is intrinsically determined by the capability of designing the retrieval process as the time-reversal of the storage dynamics.

Q 11.16 Wed 16:30 P

On the Advantage of Sub-Poissonian Single Photon Sources in Quantum Communication — •Daniel Vajner, Timm Gao, and Tobias Heindel — Institute of Solid State Physics, Technical University Berlin, 10623 Berlin

Quantum Communication in principle enables a provably secure transmission of information. While the original protocols envisioned single photons as the quantum information carrier [1], nowadays implementations and commercial realizations make use of attenuated laser pulses. There are, however, a number of advantages of using single photon sources. They are not limited by the Poisson statistics and suffer less under finite-key length corrections [2]. In addition, the second order interference visibility of true single photons can exceed the classical value of 50% which will be benefitial for all quantum information processing schemes, as well as measurment device independent QKD schemes, that rely on Bell state measurements of photons from different sources [3]. Given recent advances in the development of engineered semiconductor QD-based light sources, harnessing these advantages is within reach. We present an overview of different scenarios in which employing single photon sources improves the communication rate and distance.

[1] Bennett et al. *Proceedings of the IEEE International Conference on Computers, Systems and Signal Processing* (1984)
[2] Cai et al. *New Journal of Physics* 11.4 (2009): 045024
[3] Mandel, L. *Physical Review A* 28.2 (1983): 929

Q 11.17 Wed 16:30 P

Multi-rail optical memory in warm Cs vapor — •Leon Messner[1,2,3], Luisa Esguerra[2,3], Mustafa Gündoğan[1,2], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Str. des 17 Juni 135, 10623 Berlin, Germany

Mapping quantum states of light onto long-lived matter excitations is considered an important step in the realization of optical quantum communication and computation architectures [1]. In quantum communication the manifold approaches to this task are subsumed under the topic of quantum memories [2]. Multiplexing of these memories helps to achieve higher communication rates per link and is especially important on links that exhibit high loss [3].

We present a multi-rail EIT memory [4] within a single Cs vapor cell at room temperature. By deflecting the co-propagating signal and control beams, multiple non-interacting volumes within a single Cs vapor cell are addressed. Storing to and retrieving from randomly selected rails is then demonstrated by changing the AOM driving frequency.

[1] Kimble, H., Nature **453**, 1023 (2008)
[2] Heshami, K. et al., JModOpt **63**, 2005 (2016)
[3] Gündoğan, M. et al., arXiv:2006.10636 (2020)
[4] Wolters, J. et al., PRL, **119**, 060502 (2017)

Q 11.18 Wed 16:30 P

Toward a Photon-Photon Quantum Gate Based on Cavity Rydberg EIT — Thomas Stolz, •Hendrik Hegels, Bianca Röhr, Maximilian Winter, Ya-Fen Hsiao, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann Str. 1, 85748 Garching, Germany

All realizations of optical photon-photon quantum gates to date suffer from low efficiency [1]. Theory suggests that this limitation can be overcome using Rydberg electromagnetically induced transparency (EIT) in an optical cavity of moderate finesse [2]. We have set up a new vacuum system, which houses a cavity, in which an ultracold atomic ensemble is held in an optical dipole trap. The ensemble is cooled in multiple stages to a temperature of $0.2\,\mu$K. This low temperature is needed to achieve a long coherence time [3]. We report on the observation of cavity Rydberg EIT. This is a promising step on the way to a future realization of a photon-photon gate.

[1] K. Kieling et al. NJP 12, 013003 (2010), B. Hacker et al. Nature 536, 193 (2016), D. Tiarks et al. Nat. Phys. 15, 124 (2019).
[2] Y. Hao et al. Sci. Rep. 5, 10005 (2015), S. Das et al. PRA 93, 040303 (2016).
[3] S. Schmidt-Eberle et al. PRA 101, 013421 (2020).

Q 11.19 Wed 16:30 P

Towards Cavity-Enhanced Spectroscopy of Single Europium Ions in Yttria Nanocrystals — Timon Eichhorn[1], •Sören Bieling[1], Christian Rentschler[2], Shuping Liu[3], Alban Ferrier[3], Philippe Goldner[3], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]CFEL/DESY, 22607 Hamburg, Germany — [3]Chimie Paris Tech, 75231 Paris, France

A promising approach for realizing scalable quantum registers lies in the efficient optical addressing of rare-earth ion spin qubits in a solid state host. Within the EU Quantum Flagship project SQUARE we study Eu^{3+} ions doped into Y_2O_3 nanoparticles (NPs) as a coherent qubit material and work towards efficient single ion detection by coupling their emission to a high-finesse fiber-based Fabry-Pérot microcavity. A beneficial ratio of the narrow homogeneous line to the inhomogeneous broadening of the ion ensemble at temperatures below 10K makes it possible to spectrally address and readout single ions. The coherent control of the single ion $^5D_0-^7F_0$ transition then permits optically driven single qubit operations on the Europium nuclear spin states. A Rydberg-blockade mechanism between ions within the same nanocrystal permits the implementation of a two-qubit CNOT gate to entangle spin qubits and perform quantum logic operations. Theoretical simulations of the single and two-qubit gate operations predict fidelities of up to 98.2% and 96.5%, respectively, with current material properties. We report on our progress to experimentally implement this scheme.

Q 11.20 Wed 16:30 P

Controlling single erbium dopants in a Fabry-Perot resonator — •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

Erbium dopants exhibit unique optical and spin coherence lifetimes and show great promise for long-distance quantum networks, as their emission lies in the minimal-loss window of optical fibers. To achieve an efficient spin-photon interface for single dopants, we integrate thin host crystals into cryogenic Fabry-Perot resonators. With a Finesse of $1.2 \cdot 10^5$ we can demonstrate up to 58(6)-fold Purcell enhancement of the emission rate, corresponding to a two-level cooperativity of 530(50). Our approach avoids interfaces in the proximity of the dopants and therefore preserves the optical coherence up to the lifetime limit. [1]

Using this system, we resolve individual Erbium dopants which feature an ultra-low spectral diffusion of less than 100 kHz, being limited by the nuclear spin bath. This should facilitate frequency-multiplexed spin-qubit readout, control and entanglement, opening unique perspectives for the implementation of quantum repeater nodes.

[1] B. Merkel, A. Ulanowski, and A. Reiserer, Phys. Rev. X 10, 041025 (2020)

Q 11.21 Wed 16:30 P

A multi-site quantum register of neutral atoms with single-site controllability — •Lars Pause, Tilman Preuschoff, Stephan Amann, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Assembled arrays of neutral atoms are a versatile platform for quantum techologies. As effectively non-interacting particles with identical intrinsic properties they also feature switchable interactions when excited to Rydberg states. This makes neutral atoms well suited for quantum simulation, computation, and metrology.

We present our unique micro-optical implementation of triangular arrays of optical tweezers. Combined with a digital micromirror device (DMD), site-selective manipulation of the trapping potentials is possible while utilizing the robust architecture of microlens-based systems. The addition of a single movable optical tweezer enables atom sorting for achieving defect-free structures of individual atoms. We also discuss recent work with microlens arrays fabricated by femtosecond direct laser writing [1].

In addition, we present our open-source digital controllers for laser frequency and intensity stabilization [2]. Using the STEMlab (originally Red Pitaya) platform we achieve a control bandwidth of up to 1.25 MHz resulting in a laser line width of 52(1) kHz (FWHM) and intensity control to the $1 \cdot 10^{-3}$ level.

[1] D. Schäffner et. al., Opt. Express **28**, 8640-8645 (2020).
[2] T. Preuschoff et. al., Rev. Sci. Instrum. **91**, 083001 (2020).

Q 11.22 Wed 16:30 P

Ultra-stable open micro-cavity platform for closed cycle cryostats — •Michael Förg[1,2], Jonathan Noé[1,2], Manuel Nutz[1,2], Theodor Hänsch[2], and Thomas Hümmer[1,2] — [1]Qlibri project, Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany — [2]Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany

We present a fully 3D-scannable, yet highly stable micro-cavity setup, which features a stability on the sub-pm scale under ambient conditions and unprecedented stability inside closed-cycle cryostats. An optimized mechanical geometry, custom built stiff micro-positioning, vibration isolation and fast active locking enables quantum optics experiments even in the strongly vibrating environment of closed-cycle cryostats. High-finesse, open-access, mechanical tunable, optical micro-cavities offer a compelling system to enhance light matter interaction. Combining a scannable microscopic fiber-based mirror and a macroscopic planar mirror creates a versatile experimental platform. A variety of solid-state quantum systems can be brought onto the planar mirror, addressed individually, and (strongly) coupled to the cavity. With mechanical tuning of the cavity length, the resonance frequency can be adapted to the quantum system. However, the flexibility of the mechanical degrees of freedom bears also downsides. Inside close-cycle cryostats, fluctuations of the cavity length on the picometer scale are often enough to prevent the use of high-finesse cavities for quantum optics experiments. Our system enables the use of a flexible micro-cavity system for quantum applications even in this adversarial environment.

Q 11.23 Wed 16:30 P

Engineering of Vibrational dynamics in a two-dimensional array of trapped ions — •Deviprasath Palani, Philip Kiefer, Lennart Guth, Florian Hasse, Robin Thomm, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of Freiburg

Trapped ions present a promising system for quantum simulations [1]. Surface-electrode traps in contrast to conventional ion traps offer the advantage of scalability to larger system size and dimension while maintaining individual control: Dedicated radio-frequency electrode shapes allow the creation of two-dimensional trap arrays [2] while control electrodes allow localized manipulation of the trapping potential by tuning motional frequencies and mode orientations [3]. Our setup consists of an array of three Mg+ ions individually trapped in an equilateral triangle with 40 μm inter-site distance. We present the first realization of inter-site coupling, until now only realized for 1D arrangements. We demonstrate its tuning in real-time and show interference of large coherent states [4] and employ modulation of the local trapping potentials to realize phonon-assisted tunneling between adjacent sites [5]. Furthermore, with an identical prototype setup, we investigate methods such as surface cleaning to decrease noise field contributions [6].

[1] K. R. Brown et al., Nature 471 (2011). [2] T. Schaetz et al., N. J. Phys. 15, 085009 (2013). [3] M.Mielenz et al., Nat. Com. 7, 11839 (2016). [4] Hakelberg, F. et al. Phys. Rev. Lett. 123, 100504 (2019). [5] Kiefer, P. et al. Phys. Rev. Lett. 123, 213605 (2019). [6] U. Warring et al., Adv. Quantum Technol. 2020, 1900137.

Q 11.24 Wed 16:30 P

Characteristic dynamics of the bosonic quantum east model — •Andreas Geissler and Juan Garrahan — School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

Kinetically constrained models like the East model are among the simplest systems to give insight into the dynamics of glass formers. In these models local spin flips are only possible if neighboring spins satisfy a condition, for example in the East model if the neighbor to the left points up. Here, we consider a bosonic quantum version of the East model using the Holstein-Primakoff-transformation. A comparison of exact diagonalzation and the flucuation operator expansion reveals a ground state phase diagram reminiscent of the spin half case. Using a Gross-Pitaevskii like limit for large spin we are able to perform dynamics for large system sizes. These reveal different dynamical regimes. We use open boundary conditions with the first site fixed to any non-zero occupation. We then observe two types of chaotic behavior in the active regime, depending on the energy of the local generator, and nontrivial localization dynamics in the inactive regime.

[1] M.C. Banuls et al., PRL, 123, 200601 (2019)

Q 11.25 Wed 16:30 P

Optimized diamond inverted nanocones for enhanced color center to fiber coupling — •Cem Güney Torun[1], Philipp-Immanuel Schneider[2,3], Martin Hammerschmidt[2,3], Sven Burger[2,3], Tommaso Pregnolato[1,4], Joseph. H. D. Munns[1], and Tim Schröder[1,4] — [1]Integrated Quantum Photonics, Humboldt-Universität zu Berlin, Berlin — [2]JCMwave GmbH, Berlin — [3]Zuse Institute Berlin (ZIB), Berlin — [4]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Fiber coupling of the emission from color centers in diamond, a promising candidate for quantum nodes, is challenging due to the mode mismatches and reduced light outcoupling caused by the total internal reflections. Nanostructures are popular tools utilized to overcome these challanges. Nevertheless, while the fiber coupling properties are crucial for a single mode of indistinguishable photons, this performance of nanostructures is rarely investigated. Here, we simulate the emission of color centers and overlap of this emission with the fundamental fiber modes for a novel nanostructure called **inverted nanocone**. Using different figures of merit, the parameters are optimized to maximize fiber coupling efficiency, free-space collection efficiency or emission rate enhancement. The optimized inverted nanocones show promising results, with 66% fiber coupling or 83% free-space collection efficiency at the tin-vacancy center zero-phonon line wavelength of 619 nm. For maximum emission rate into a fiber mode, a design with a Purcell factor of 2.34 is identified. Moreover, these designs are analyzed for their broadband performance and robustness against fabrication errors.

Q 11.26 Wed 16:30 P

Construction of a reliable laser light source for resonant excitation of tin-vacany centers — •Franziska M. Herrmann[1], Joseph H.D. Munns[1], and Tim Schröder[1,2] — [1]Integrated Quantum Photonics, Institut für Physik, Humboldt-Universität zu Berlin, Berlin — [2]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Tin-vacancy colour centres in diamond are promising candidates for nodes in quantum networks, due to their suitable optical and spin properties. However, with a zero phonon line wavelength of 619 nm, resonant excitation cannot be achieved easily by commercially available and affordable laser systems. At 1238 nm however, suitable narrowband lasers are available and the targeted 619 nm can be reached by frequency doubling. The conversion is achieved based on second harmonic generation in an MgO:PPLN crystal pumped with infrared laser light. Here we introduce the setup and investigate the stability and tunability of this laser system and demonstrate how several PID controlled feedback loops can ensure usability for future quantum control applications.

Q 11.27 Wed 16:30 P

Shorcuts to adiabaticity with quantum non-demolition measurements — •Raphael Menu and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, German

The realization of quantum adiabatic dynamics is at the core of implementations of adiabatic quantum computers. One major issue is to efficiently compromise between the long time scales required by the adiabatic protocol and the detrimental effects of the environment, which set an upper bound to the time scale of the operation. In this work we propose a protocol which achieves fast adiabatic dynamics by coupling the system to an external environment by the means of a quantum-non-demolition (QND) Hamiltonian. We analyse the infidelity of adiabatic transfer for a Landau-Zener problem in the presence of QND measurement, where the qubit couples to a meter which in turn quickly dissipates. We analyse the protocol's fidelity as a function of the strength of the QND coupling and of the relaxation time of the meter. In the limit where the decay rate of the ancilla is the largest frequency scale of the dynamics, the QND coupling induces an effective dephasing in the adiabatic basis. Optimal conditions for adiabaticity are found when the coupling with the meter induces dissipative dynamics which suppresses unwanted diabatic transitions.

Q 12: Quantum Technology

Time: Wednesday 16:30–18:30 Location: P

Q 12.1 Wed 16:30 P

Nanofabricated and integrated colour centres in SiC with excellent spin-optical coherence — •Florian Kaiser[1], Charles Babin[1], Rainer Stöhr[1], Naoya Morioka[1], Tobias Linkewitz[1], Timo Steidl[1], Raphael Wörnle[1], Di Liu[1], Erik Hesselmeier[1], Vadim Vorobyov[1], Andrej Denisenko[1], Mario Hentschel[1], Christian Gobert[2], Patrick Berwian[2], Georgy Astakhov[3], Wolfgang Knolle[4], Sridhar Majety[5], Pranta Saha[5], Marina Radulaski[5], Nguyen Tien Son[6], Jawad Ul-Hassan[6], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, Germany — [2]Fraunhofer IISB, Erlangen, Germany — [3]HZDR, Dresden, Germany — [4]IOM, Leipzig, Germany — [5]University of California, Davis, USA —

[6]Linköping University, Sweden

We demonstrate that silicon vacancy (VSi) centres in semiconductor silicon carbide (SiC) are prime candidates for scalable integration into nanophotonic cavities. To this end, we show:

1.) Low-energy ion-assisted implantation without degradation of spin-optical coherences.

2.) Reliable operation of VSi centres in nanophotonic waveguides with little to no degradation of spin-optical coherences.

3.) Operation of VSi centres at high temperatures (T=20 K), while coherently controlling multiple nuclear spin qubits with near unity fidelity.

Our work represents a major step forward towards integrated multi-spin-multi- photon interfaces for distributed quantum computation and communication.

Q 12.2 Wed 16:30 P

Magnetometry on spin-crossover complexes using nitrogen-vacancy centers in nanodiamonds — •Isabel Manes[1], Jonas Gutsche[1], Tim Hochdörffer[1], Gereon Niedner-Schatteburg[2], and Artur Widera[1] — [1]Physics Department, Technische Universtät Kaiserslautern und Forschungszentrum OPTIMAS, 67663 Kaiserslautern — [2]Chemistry Department, Technische Universtät Kaiserslautern, Erwin-Schrödinger-Str. 52 67663 Kaiserslautern

Using various measurement protocols, the nitrogen-vacancy (NV) center's spin state can be optically initialized and read out. Magnetically, electrically and thermally sensitive, NV centers in nanodiamonds have been used as multipurpose nanoscale sensors.

Here, we present the application of NV centers as magnetic-field sensors to detect changes of magnetic fields caused by the spin transition of a chemical spin-crossover (SCO) complex. The examined polymeric Fe(II)-SCO complex is expected to switch from its diamagnetic low-spin state of $S = 0$ to a paramagnetic high-spin state of $S = 2$ per Fe(II) ion at $\sim 47\,^{\circ}$C. This thermally-induced SCO would cause a change in a local magnetic field. Using a simple model, we estimate this change to be in the order of 1 mT. Experimentally, we deposit nanodiamonds of approximately 700 nm average size and with less than 1 ppm NV centers on a thin-layer sample of the SCO complex. We perform temperature-dependent CW optically detected magnetic resonance spectroscopy using a self-built temperature-controlled sample holder. With temperatures rising above 47 °C, resonance frequencies are expected to shift in the MHz range.

Q 12.3 Wed 16:30 P

GHz Rydberg Rabi flopping towards an on-demand single-photon source — •Max Mäusezahl[1], Annika Belz[1], Florian Christaller[1], Felix Moumtsilis[1], Hadiseh Alaeian[2], Harald Kübler[1], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, West Lafayette, IN 47907, USA

Fast coherent control of Rydberg excitations is a key component for quantum logic gates [1] and on-demand single-photon sources based on the Rydberg blockade as demonstrated for room-temperature rubidium atoms in a micro-cell [2]. We pursue an evolution of this single-photon source by employing state-of-the-art 1010 nm fiber amplifiers [3] to drive a Rydberg excitation via the 6P intermediate state. This, together with nanosecond density-switching light-induced atomic desorption (LIAD) pulses, will allow MHz repetition rates and significantly higher photon yields. Here we report on our current observation of GHz Rabi flopping to 32S and 40S Rydberg states. Such excitation timescales also pave the way towards fast optimal control methods for high fidelity Rydberg logic gates.

[1] Saffman, Journal of Physics B 49, 20 (2016)
[2] Ripka et al., Science 362, 6413 (2018)
[3] de Vries et. al., Optics Express 28, 12 (2020)

Q 12.4 Wed 16:30 P

Autonomous Single Atom Heat Engine — •Bo Deng, Moritz Göb, Max Masuhr, Kilian Singer, and Daqing Wang — Institut für Physik, Universität Kassel, Kassel, Germany

Here, we present our recent advances towards realizing an autonomous heat engine with a single atomic ion. The engine is based on a single $^{40}Ca^{+}$-ion confined in a tapered Paul trap. We propose implementing thermal baths with two tightly focused laser beams at different frequency detunings from the Doppler cooling transition. Furthermore, we employ a sub-Hertz linewidth laser system to address the $4^2S_{1/2}$ to $3^2D_{5/2}$ quadrupole transition. This will be used to perform sideband resolved ground state cooling, enabling the utilization of quantum reservoirs[1] to drive the single-atom heat engine.

[1]A. Levy, M. Göb, B. Deng, K. Singer, E. Torrontegui and D. Wang, *Single-atom Heat Engine as A Sensitive Thermal Probe*, New Journal of Physics **22.9**(2020)

Q 12.5 Wed 16:30 P

A fiber-based endoscope with integrated microwave antenna for magnetic sensing — •Stefan Dix[1], Jonas Gutsche[1], Erik Waller[2], Georg von Freymann[1,2], and Artur Widera[1] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, 67663 Kaiserslautern, Germany

Fiber-based endoscopes are established and widely applied as local fluorescence detectors for various samples, replacing bulky microscopes. Recently, fiber-based sensors with integrated diamonds containing nitrogen-vacancy (NV) centers have been developed. For magnetic field sensing using NV centers, a microwave field addresses a transition in the NV center. The microwave fields needed close to the fiber tip are usually created using thin wires.

Here, we present an integrated fiber-based sensor with a direct-laser-written (DLW) silver antenna structure on a multimode-fiber facet with a 50 μm core diameter and the implementation of a static magnetic field with an optional ring magnet around the fiber for the measurement of low magnetic fields. We present the characteristics of the applied microwave field, which we measure via network analysis as well as Rabi spectroscopy of diamonds with a diameter of $\sim$15 μm containing $\sim$3.5 ppm NV centers. We find a sensitivity of a few 100 nT/Hz$^{1/2}$ of our sensor. Our endoscope thus points toward possible applications for remote measurements of vector-magnetic fields.

Q 12.6 Wed 16:30 P

Generation of Optical Pulses for Solid-State Qubit Control — •Kilian Unterguggenberger[1], Laura Orphal-Kobin[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institute, Berlin, Germany

Many quantum information protocols proposed for solid-state qubits require coherent optical pulses as an elementary tool for, e.g., single-shot readout and spin-photon entanglement. Pulse lengths on the nanosecond timescale and pulse areas matching the respective Rabi frequency are required to address, for example, diamond color centers.

To achieve a short rise time and a high extinction ratio, we shape the light emitted by a narrow-bandwidth diode laser with an electro-optical modulator (EOM) in a Mach-Zehnder interferometer configuration. While commonly utilized for telecommunication with infrared light, operating an EOM at shorter, visible wavelengths is challenging due to the excitation of impurity sites in the waveguide material. The induced charge diffusion creates an internal electric field, causing the operation point of the modulator to drift. We stabilize the system using an active control feedback loop and characterize its performance. A fully polarization-maintaining fiber-coupled beam path makes the system flexible and enables precise pulse area adjustments using polarization optics.

Q 13: Ultra-cold atoms, ions, and BEC (joint session A/Q)

Time: Wednesday 16:30–18:30 Location: P

Q 13.1 Wed 16:30 P

Observation of a universal entropy behaviour for impurities in an ultracold bath — •Silvia Hiebel, Jens Nettersheim, Julian Fess, Sabrina Burgardt, Daniel Adam, and Artur Widera — Physics Department and State Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern, Germany

Nonequilibrium systems usually thermalize by gradually increasing their entropy to a new equilibrium state. For systems very far from equilibrium, however, another pathway has been predicted[1], where rapidly a state of high entropy, close to the maximal entropy possible for this system, is reached. The dynamic following this so-called prethermal memory loss is predicted to be universal.

We experimentally realize such nonequilibrium dynamics in the spin manifold of single Cs impurities undergoing spin-exchange collisions with a large Rb bath. The maximum entropy of the quantum spin distribution is reached after a few spin-exchange collisions starting from a spin-polarized, low entropy state. Rescaling the following spin-distribution dynamics when maximum entropy is reached, we find the trace of each spin state identical, independent of the initially prepared spin state. We analyse and describe these mechanisms in terms of the drift and diffusion of the quantum spin distribution. Our work thus illustrates the existence of universal, prethermal dynamics in open quantum systems far from equilibrium.

[1]Ling-Na Wu and André Eckardt, PRB 101, 220302 (2020)

Q 13.2 Wed 16:30 P

Exploring p-Wave Feshbach Resonances in ultracold ^{6}Li and ^{6}Li-^{133}Cs — •Manuel Gerken[1], Kilian Welz[1], Binh Tran[1], Eleonora Lippi[1], Stephan Häfner[1], Lauriane Chomaz[1], Bing Zhu[3], Eberhard Tiemann[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, University of Heidelberg — [2]Institut für Quantenoptik, University of Hannover — [3]University of Science and Technology of China

We report on the observation of spin-rotation coupling in p-wave Feshbach resonances in 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 $m_l \pm 1$ components to electron spin-rotation coupling. We present and estimation of the spin-rotation coupling by describing the weakly bound close channel molecular state with the perturbative multipole expansion, valid in the range $R > R_{LR}$, where R is the inter nuclear distance and R_{LR} is the LeRoy radius. The underestimation of the coupling reveals a significant contribution of the molecular wave function at short inter-nuclear distances $R < R_{LR}$. We also present measurements of spin-spin coupling in p-wave Feshbach resonances in a ^{6}Li mixture and calculations of collisional cooling close to a ^{6}Li p-wave Feshabch resonance.

Q 13.3 Wed 16:30 P

Single-atom quantum otto motor driven by atomic collisions — •Jens Nettersheim[1], Sabrina Burgardt[1], Daniel Adam[1], Eric Lutz[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany — [2]Institute for Theoretical Physics I,University of Stuttgart, Stuttgart, Germany

Recent advances in controlling nanoscopic objects suggest the realizations of machines exploiting quantum properties. However, the increasing importance of fluctuations in quantum systems calls into question whether such devices can combine high efficiency, high output power, and small power fluctuations. Experimentally, we realize a stable quantum-Otto engine by immersing single Cs atoms into an ultracold Rb bath. Employing inelastic spin-exchange interactions, we maximize output power while minimizing power fluctuations owing to the finite quantum spin space forming the machine. We investigate the population fluctuations of the system as a function of its heat exchange and output power. For our system with seven quantum-spin levels, the initial and final states are polarized. They show no population fluctuations, in contrast to an infinite-level harmonic oscillator system at a given temperature. We analyze in which parameter range the quantum-spin engine can outperform harmonic oscillator systems in terms of output power and power fluctuations.

Q 13.4 Wed 16:30 P

Long-distance transport of ultracold gases in an optical dipole trap utilizing focus-tunable lenses — •Maximilian Kaiser[1,2], Sian Barbosa[1], Jennifer Koch[1], Felix Lang[1], Benjamin Nagler[1], and Artur Widera[1] — [1]Physics Department, University of Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern — [2]Physics Institute, Heidelberg University, Im Neuenheimer Feld 226, 69120 Heidelberg

In order to integrate novel optical techniques into packed quantum gas experiments, different transport approaches have been developed to bridge the gap between different sections of the experimental vacuum chamber.

We report on the realization of an optical dipole trap (ODT) transport system for ultracold gases based upon [1]. A lens system around a commercially available focus-tunable lens shifts the focus of a red-detuned ODT beam through the vacuum chamber, effectively moving trapped atoms while maintaining constant trapping conditions throughout the entire transport. We have developed a scheme for precise alignment, characterized the focal shift, and studied its spatial stability. We have verified its functionality and found spatial stability of the focus on the micrometer scale. The system is integrated into a lithium-6 quantum-gas experiment, where the transport trap is loaded with efficiencies of more than 90% for both BECs and thermal gases. Ultimately, we demonstrate the transport of an ultracold quantum gas over a distance of 507mm.

[1] Julian Léonard et al., New J. Phys. 16 093028 (2014)

Q 13.5 Wed 16:30 P

Exciton-polaron-polariton condensation — •Miguel Bastarrachea-Magnani[1,2], Aleksi Julku[2], Arturo Camacho-Guardian[3], and Georg Bruun[2] — [1]Physics Department, Universidad Autonoma Metropolitana-Iztapalapa, San Rafael Atlixco 186, C.P. 09340 CDMX, Mexico — [2]Center for Complex Quantum Systems, Department of Physics and Astronomy, Aarhus University, Ny Munkegade, DK-8000 Aarhus C, Denmark — [3]T.C.M. Group, Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge, CB3 0HE, U.K

Exciton-polaritons created in microcavity semiconductors are highly tunable quantum states that, thanks to their hybrid character, allow the transfer of features between light and matter. Polariton interactions make it possible to create quantum fluids, exhibiting macroscopic quantum states like condensation and superfluidity. Because of this they constitute a fruitful field to exchange ideas with atomic physics and to unveil novel no-linear optical effects. Recent experiments have demonstrated that, by doping the semiconductor with itinerant electrons, the exciton-polaritons get dressed in electronic excitations to create polarons, opening a new venue to explore Bose-Fermi mixtures. Here, we describe the condensation of exciton-polaritons in the presence of a two-dimensional electron gas by employing a non-perturbative many-body theory to treat exciton-electron correlations combined with a non-equilibrium theory for the condensate.

Q 13.6 Wed 16:30 P

A quantum heat engine driven by atomic collisions — •Sabrina Burgardt[1], Quentin Bouton[1], Jens Nettersheim[1], Daniel Adam[1], Eric Lutz[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany. — [2]Institute for Theoretical Physics I, University of Stuttgart, Stuttgart, Germany.

Quantum heat engines are subjected to quantum fluctuations related to their discrete energy spectra. Such fluctuations question the reliable operation of thermal machines in the quantum regime. Here, we realize an endoreversible quantum Otto cycle in the large quasi-spin states of Cesium impurities immersed in an ultracold Rubidium bath.

We employ quantum control to regulate the direction of heat transfer that occurs via inelastic spinexchange collisions. We further use full-counting statistics of individual atoms to monitor quantized heat exchange between engine and bath at the level of single quanta, and additionally evaluate average and variance of the power output. We optimize the performance as well as the stability of the quantum heat engine, achieving high efficiency, large power output and small power output fluctuations.

Q 13.7 Wed 16:30 P

Design of high-field coils for Feshbach resonances and rapid ramps in lithium-6 — •Felix Lang[1], Maximilian Kaiser[1,2], Sian Barbosa[1], Jennifer Koch[1], Benjamin Nagler[1], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universitaet Kaiserslautern, Germany — [2]Physics Institute, Heidelberg University, Im Neuenheimer Feld 226, 69120 Heidelberg

Realizing the BEC-BCS crossover in ultracold fermionic gases of lithium-6 requires high magnetic fields to address the Feshbach resonance at 832G [1]. One important tool for the control of such systems is the use of rapid magnetic-field ramps which enables, e.g., the detection of fermionic pair condensates [2].

Here I report on the design of a low-inductance Helmholtz coil pair for high currents up to 400A which complies with these contrary conditions. Numerical calculations of the magnetic field are used to optimize the coil geometry, while complimentary electrical-circuit simulations provide insight into attainable switching times. In addition, I discuss the cooling infrastructure and temperature surveillance, as well as the elaborate manufacturing process of the coils.

[1] R. Grimm, in Proceedings of the International School of Physics "Enrico Fermi", Vol. 164, edited by C. S. M. Inguscio W. Ketterle (2007) pp. 413-462.

[2] M. W. Zwierlein, C. H. Schunck, C. A. Stan, S. M. F. Raupach, and W. Ketterle, Physical Review Letters 94, 180401 (2005).

Q 13.8 Wed 16:30 P

Towards Quantum Simulation of Light-Matter Interfaces with Strontium Atoms in Optical Lattices — •Jan Trautmann[1,2], Annie Jihyun Park[1,2], Valentin Klüsener[1,2], Dimitry Yankelev[1,2], Yilong Yang[1,2], Dimitrios Tsevas[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2] — [1]MPQ, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]MCQST, 80799 München, Germany — [3]LMU, Schellingstraße 4, 80799 München, Germany

In the last two decades, quantum simulators based on ultracold atoms in optical lattices have successfully emulated strongly correlated condensed matter systems. With the recent development of quantum gas microscopes, these quantum simulators can now control such systems with single site resolution. Within the same time period, atomic clocks have also started to take advantage of optical lattices by trapping alkaline-earth-metal atoms such as Sr, and interrogating them with precision and accuracy at the 2e-18 level. Here, we report on progress towards a new quantum simulator that combines quantum gas microscopy with optical lattice clock technology. We have developed in-vacuum buildup cavities with large mode volumes that will be used to overcome the limits to system sizes in quantum gas microscopes. We imaged the intensity profile of the two orthogonal cavity modes of the in-vacuum buildup cavity by loading ultracold strontium atoms in a lattice created by those modes. By using optical lattices created in this buildup cavity that are state-dependent for the clock states, we aim to emulate strongly-coupled light-matter-interfaces.

Q 13.9 Wed 16:30 P

Quantum Gas Magnifier for sub-lattice-resolved imaging of 3D systems — •Luca Asteria[1], Henrik P. Zahn[1], Marcel N. Kosch[1], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut for Laserphysics, Hamburg — [2]The Hamburg Centre for Ultrafast Imaging — [3]Zentrum für Optische Quantentechnologien, Hamburg

Imaging is central for gaining microscopic insight into physical systems, but direct imaging of ultracold atoms in optical lattices as modern quantum simulation platform suffers from the diffraction limit as well as high optical density and small depth of focus. We introduce a novel approach to imaging of quantum many-body systems using matter wave optics to magnify the density distribution prior to optical imaging, allowing sub-lattice spacing resolution in three-dimensional systems. Combining the site-resolved imaging with magnetic resonance techniques for local addressing of individual lattice sites, we demonstrate full accessibility to local information and local manipulation in three-dimensional optical lattice systems. The method opens the path for spatially resolved studies of new quantum many-body regimes including exotic lattice geometries.

Q 13.10 Wed 16:30 P

Simulation of the Quantum Rabi Model in the Deep Strong-Coupling Regime with Ultracold Rubidium Atoms — •Stefanie Moll[1], Geram Hunanyan[1], Johannes Koch[1], Martin Leder[1], Enrique Rico[2], Enrique Solano[2], and Martin Weitz[1] — [1]University of Bonn, Bonn, Germany — [2]University of the Basque Country, Bilbao, Spain

When considering light-matter interaction with a magnitude of the coupling strength that approaches the optical resonance frequency, one enters the deep strong-coupling regime, where the approximations of the Jaynes Cummings Model do not hold anymore. Theory has predicted non-intuitive dynamics in the limit of the full QRM-Hamiltonian becoming applicable.

Our experimental implementation of the quantum Rabi model uses ultracold rubidium atoms in an 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 the oscillations of the atoms in an optical dipole trapping potential.

We observe atomic dynamics in the deep strong-coupling regime, yielding high excitation numbers of the oscillator modes being created out of the vacuum. The current status of experimental results will be presented.

Q 13.11 Wed 16:30 P

A high-resolution Ion Microscope to Probe Quantum Gases — •Moritz Berngruber, Nicolas Zuber, Viraatt Anasuri, Yiquan Zou, Florian Meinert, Robert Löw, and Tilman Pfau — Universität Stuttgart, Germany

On our poster, we present a high-resolution ion microscope, which is designed as a versatile tool to study cold quantum gases, ground-state ensembles, Rydberg excitations, and ionic impurities. The ion microscope consists of three electrostatic lenses that allow to image charged particles on a delay-line detector.

The microscope provides a highly tunable magnification, ranging from 200 to over 1500, a spatial resolution better than 200 nm and a depth of field of more than 70 μm. These properties enable the study of bulk quantum gases and phenomena ranging from microscopic few body processes to extended many-body systems. By additionally evaluating the time-of-flight to the detector, it is possible to obtain 3D-images of the cold atomic cloud.

Excellent electric field compensation allows us to study highly excited Rydberg systems and cold ion-atom hybrid systems. We will present recent results in the field of ion-atom hybrid systems, where the interaction between ions and Rydberg atoms results in a novel long-range atom-ion Rydberg molecule.

Q 13.12 Wed 16:30 P

All-optical production of K-39 BECs utilizing tunable interactions — •Alexander Herbst, Henning Albers, Sebastian Bode, Knut Stolzenberg, Ernst Rasel, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover

The all-optical production of potassium-39 BECs is of large interest for the field of guided atom interferometry and its application for quantum inertial sensors. Contrary to other setups and atomic species this combination allows for the use of small external magnetic fields to control atomic interactions for the suppression of dephasing effects. However, the negative background scattering length and the narrow hyperfine splitting of potassium-39 pose a major experimental challenge.

We report on the loading of a crossed optical dipole trap at 2 um wavelength and the subsequent generation of a BEC. By using a gray molasses technique on the D1 line we are able to directly load the trap without the need for magnetic trapping as an intermediate step.

For evaporation we utilize time-averaged optical potentials to control the trap frequencies in combination with Feshbach resonances to change the atomic scattering length to positive values. We realize BECs of up to $2 \cdot 10^5$ atoms after a 4 second long evaporation ramp and more than $5 \cdot 10^4$ atoms after less than 1 second. We discuss our experimental sequence, the current limitations of our setup and the perspectives for producing BECs of higher atom number with the fast ramp.

Q 13.13 Wed 16:30 P

Trapping Ion Coulomb Crystals in Optical Lattices — •Daniel Hönig[1], Fabian Thielemann[1], Joachim Welz[1], Wei Wu[1], Leon Karpa[2], Amir Mohammadi[1], and Tobias Schätz[1] — [1]Albert-Ludwigs Universität Freiburg — [2]Leibniz Universität Hannover

Optically trapped ion Coulomb crystals are an interesting platform for quantum simulations due to the long range of the Coulomb interaction as well as the state dependence of the optical potential. Optical lattices expand the possible application of this platform by trapping the ions in seperate potential wells as well as giving optical confinement along the axis of the beam. In the past we presented the succesfull trapping of a single ion in a one dimensional optical lattice as well as of ion coulomb crystals in a single beam optical dipole trap.

In this Poster, we present recent advancements in trapping of Ba138+ ions in a one dimensional optical lattice at a wavelength of 532nm and report the first successfull trapping of small ion coulomb crystals ($N \leq 3$) in this lattice. We compare trapping results between the lattice and a single beam optical dipole trap and investigate the effect of an axial electric field on the trapping probability of a single ion to demonstrate the axial confinement of the ion in the optical lattice.

Q 13.14 Wed 16:30 P

Quantum droplet phases in extended Bose-Hubbard models with cavity-mediated interactions — •Peter Karpov[1,2] and Francesco Piazza[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]National University of Science and Technology "MISiS", Moscow, Russia

Extended Bose-Hubbard (eBH) models have been studied for more than 30 years. We numerically found a set of new phases present in generic eBH models with competing long-range attractive and local repulsive interactions [1]. These are different phases of self-bound quantum droplets. We observe a complex sequence of transitions between droplets of different sizes, and of compressible (superfluid or supersolid) as well as incompressible (Mott or density-wave insulating) nature, governed by the competition between the local repulsion and the finite-range attraction.

We propose a concrete experimental implementation scheme based on the multimode optical cavities. The analogous infinite-range model was experimentally realized by the Zürich group [2] using single-mode optical cavities. The recent progress with multimode optical cavities by the Stanford group [3] makes it possible to realize the eBH model with tunable finite-range sign-changing interactions.

[1] P. Karpov, F. Piazza, arXiv:2106.13226 (2021).
[2] R. Landig et al, Nature **532**, 476 (2016).
[3] V. Vaidya et al, Phys. Rev. X **8**, 011002 (2018).

Q 13.15 Wed 16:30 P

Density Fluctuations across the Superfluid-Supersolid Phase Transition in a Dipolar Quantum Gas — •Jan-Niklas Schmidt[1], Jens Hertkorn[1], Mingyang Guo[1], Kevin Ng[1], Sean Graham[1], Paul Uerlings[1], Tim Langen[1], Martin Zwierlein[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]MIT-Harvard center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Supersolidity is a counter-intuitive state of matter that simultaneously shows superfluid flow and crystalline order. Dipolar quantum gases confined in elongated trapping geometries feature an interaction induced modulational instability driven by the softening of a roton excitation that eventually get stabilized by quantum fluctuations. By directly measuring density fluctuation in situ we extract the static structure factor across the transition, identify the roton modes as the dominant cause of the crystallization, and simultaneously observe BEC and crystal phonons on the supersolid side of the transition as a hallmark of supersolidity. An advanced study in circularly symmetric trapping geometries reveals the role of angular roton excitations in the crystallization process to two-dimensional droplet arrays. This understanding forms an important step toward the realization of a two-dimensional dipolar supersolid marking just the starting point to a rich phase diagram of structured patterns including novel exotic phases such as supersolid honeycomb and amorphous labyrinthine phases.

Q 13.16 Wed 16:30 P

Formation of spontaneous density-wave patterns in DC driven lattices — •Henrik Zahn, Vijay Singh, Luca Asteria, Marcel Kosch, Lukas Freystatzky, Klaus Sengstock, Ludwig Mathey, and Christof Weitenberg — Universität Hamburg, Hamburg, Deutschland

Driving a many-body system out of equilibrium induces phenomena such as the emergence and decay of transient states. This can manifest itself as pattern and domain formation. The understanding of these phenomena expands the scope of established thermodynamics into the out-of-equilibrium domain. Here, we study the out-of-equilibrium dynamics of a bosonic lattice model subjected to a strong DC field, realized as ultracold atoms in a strongly tilted triangular optical lattice. We observe the emergence of pronounced density wave patterns – which spontaneously break the underlying lattice symmetry – as well as their domains using a novel single-shot imaging technique with single-site resolution in three-dimensional systems. We explain the dynamics as arising from center-of-mass-conserving pair tunneling processes, which appear in an effective description of the tilted Hubbard model. More broadly, we establish the far out-of-equilibrium regime of lattice models subjected to a strong DC field, as an exemplary and paradigmatic scenario for transient pattern formation.

Q 13.17 Wed 16:30 P

Quantum gas microscopy of Kardar-Parisi-Zhang superdiffusion — •David Wei[1,2], Antonio Rubio-Abadal[1,2], Bingtian Ye[3], Francisco Machado[3,4], Jack Kemp[3], Kritsana Srakaew[1,2], Simon Hollerith[1,2], Jun Rui[1,2], Sarang Gopalakrishnan[5,6], Norman Y. Yao[3,4], Immanuel Bloch[1,2,7], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Germany — [3]University of California, Berkeley, USA — [4]Lawrence Berkeley National Laboratory, California, USA — [5]The Pennsylvania State University, Pennsylvania, USA — [6]College of Staten Island, New York, USA — [7]Ludwig-Maximilians-Universität, Munich, Germany

The Kardar-Parisi-Zhang universality class describes the coarse-grained dynamics of numerous classical stochastic models. Surprisingly, the emergent hydrodynamics of spin transport in the one-dimensional (1D) quantum Heisenberg model was recently conjectured to fall into this class. We test this conjecture experimentally in a cold-atom quantum simulator in spin chains of up to 50 spins by studying the relaxation of domain walls. We find that domain-wall relaxation indeed scales with the superdiffusive KPZ dynamical exponent z=3/2. By probing dynamics in 2D and by adding a net magnetization, we verify that superdiffusion requires both integrability and a non-abelian SU(2) symmetry. Finally, we leverage the single-spin-sensitive detection enabled by our quantum-gas microscope to measure spin-transport statistics, which yields a clear signature of the non-linearity that is a hallmark of KPZ universality.

Q 13.18 Wed 16:30 P

Bosonic Continuum Theory of One-Dimensional Lattice Anyons — •Martin Bonkhoff[1], Kevin Jägering[1], Sebastian Eggert[1], Axel Pelster[1], Michael Thorwart[2,3], and Thore Posske[2,3] — [1]Physics Department and Research Center Optimas,Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee149, 22761 Hamburg, Germany

Anyons with arbitrary exchange phases exist on 1D lattices in ultracold gases. Yet, known continuumt heories in 1D do not match. We derive the continuum limit of 1D lattice anyons via interacting bosons. The theory maintains the exchange phase periodicity fully analogous to 2D anyons [1]. This provides a mapping between experiments, lattice anyons, and continuum theories, including Kundu anyons with a natural regularization as a special case. We numerically estimate the Luttinger parameter as a function of the exchange angle to characterize long-range signatures of the theory and predict different velocities for left-and right-moving collective excitations.

[1] M. Bonkhoff, K. Jägering, S. Eggert, A. Pelster, M. Thorwart, and T. Posske, Bosonic continuum theory of one-dimensional lattice anyons, Phys. Rev. Lett. 126, 163201, (2021).

Q 13.19 Wed 16:30 P

Dual-species BEC for atom interferometry in space — •Jonas Böhm[1], Baptist Piest[1], Maike D. Lachmann[1], Wolfgang Ertmer[1], Ernst M. Rasel[1], and the MAIUS Team[1,2,3,4,5,6,7] — [1]Institute of Quantum Optics, LU Hanover — [2]Department of Physics, HU Berlin — [3]ZARM, U Bremen — [4]DLR Institute of Space Systems, Bremen — [5]Institute of Physics, JGU Mainz — [6]DLR Simulation and Software Technology, Brunswick — [7]FBH, Berlin

Atom interferometry is a promising tool for measurements of the gravitational constant, universality of free fall and gravitational waves. As the sensitivity scales with the squared interrogation time, conducting atom interferometry in microgravity is of great interest.

The sounding rocket mission MAIUS-1 demonstrated the first BEC and matter wave interferences of it in space. With the follow-up missions MAIUS-2 and -3, we extend the apparatus by another species to perform atom interferometry with Rb-87 and K-41, paving the way for dual-species interferometers on bord of space stations or satellites.

In this contribution, the current status of the scientific payload MAIUS-B is discussed, fulfilling the requirements of generating Rb-87 and K-41 BECs with a high repetition rate in a compact, robust, and autonomously operating setup. The atomic state preparation and the manipulation using Raman double-diffraction processes are highlighted as well.

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 13.20 Wed 16:30 P

Feshbach resonances in a hybrid atom-ion system — •Wei Wu[1], Fabian Thielemann[1], Joachim Welz[1], Thomas Walker[1], Pascal Weckesser[1,2], Daniel Hönig[1], Amir Mohammadi[1], and Tobias Schätz[1] — [1]Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

We present the first observation of Feshbach resonances between neutral atoms and ions. [1,2] While Feshbach resonances are commonly utilized in neutral atom experiments, however, reaching the ultracold regime in hybrid traps is challenging, as the driven motion of the ion by the rf trap limits the achievable collision energy. [3] We report three-body collisions between neutral 6Li and 138Ba+, where we are able to resolve individual resonances. We demonstrate the enhancement of two-body interactions through an increase in the sympathetic cooling rate of the ion by the atomic cloud, determined through optical trapping of the ion. and molecule formation evidenced by subsequent three-body losses. This paves the way to new applications such as the coherent formation of molecular ions and simulations of quantum chemistry. [4]

[1] Weckesser P, et al. arXiv preprint arXiv:2105.09382, 2021.
[2] Schmidt J, et al. Physical review letters, 2020, 124(5): 053402.
[3] Cetina M, et al. Physical review letters, 2012, 109(25): 253201.
[4] Bissbort U, et al.Physical review letters, 2013, 111(8): 080501.

Q 13.21 Wed 16:30 P

A dipolar quantum gas microscope — •Paul Uerlings, Kevin Ng, Jens Hertkorn, Jan-Niklas Schmidt, Sean Graham, Mingyang Guo, Tim Langen, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

We present the progress towards constructing a dipolar quantum gas microscope using dysprosium atoms. This new apparatus combines the long-range interactions found in dipolar quantum gases with the single-site resolution found in quantum gas microscopes. Ultracold dipolar quantum gases are a powerful and versatile platform to study quantum phenomena in and out of equilibrium. The large magnetic moment of dysprosium atoms allows for long-range and anisotropic interactions that give rise to exotic states of matter. By implementing a quantum gas microscope, microscopic details such as site occupation and site correlations will be observable. We plan to do this using magnetic atoms trapped in an ultraviolet optical lattice with a lattice spacing of a $\approx$ 180 nm. Combined with the long-range dipole interaction ($\propto 1/r^3$), the short lattice spacing will significantly increase the nearest-neighbour interaction strength to be on the order of 200 Hz (10 nK). This will allow us to study the regime of strongly interacting dipolar Bose-/and Fermi-Hubbard physics where even next-nearest-neighbour interactions could be visible. Our upcoming dipolar quantum gas microscope will enable further studies relating to quantum simulations and quantum magnetism.

Q 13.22 Wed 16:30 P

Imaging the interface of a qubit and its quantum-many-body environment — •Sidharth Rammohan[1], S.K. Tiwari[1], A. Mishra[1], A. Pendse[1], A.K. Chauhan[1,2], R. Nath[3], A. Eisfeld[4], and S. Wüster[1] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal, MP, India — [2]Department of Optics, Faculty of Science, Palacky University, 17.listopadu, Czech Republic — [3]Department of Physics, Indian Institute of Science Education and Research, Pune, India — [4]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We show that two major facets of the decoherence paradigm are experimentally accessible for a single impurity atom embedded in a Bose-Einstein condensate when the impurity is brought into an electronic superposition of two Rydberg states. Not only can the electronic decoherence of the Rydberg atom be read out by microwave interferometry, the platform also provides unique access to the accompanying entangled state of the environment. We theoretically demonstrate signatures of the latter in total atom densities during the transient time in which the impurity is becoming entangled with the medium but the resultant decoherence is not complete yet. The Rydberg impurity thus provides a handle to initiate and read-out mesoscopically entangled superposition states of Bose atom clouds affecting about 500 condensate atoms. We find that the timescale for its creation and decoherence can be tuned from the order of nanoseconds to microseconds by choice of the excited Rydberg principal quantum number ν and that Rydberg decoherence dynamics is typically non-Markovian.

Q 13.23 Wed 16:30 P

dynamics of atoms within atoms — •Shiva kant Tiwari[1], F. Engel[2], M. Wagner[3], R. Schmidt[3], F. Meinert[2], and S. Wüster[1] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal, Madhya Pradesh 462 066, India — [2]Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Recent experiments with Bose-Einstein condensates have entered a regime in which, after the excitation of a single atom into a highly excited Rydberg state, thousands of ground-state condensate atoms fill the Rydberg-electron orbit. Scattering off the electron then sets these into motion, such that one can study the quantum-many-body dynamics of atoms moving within the Rydberg atom. It has been suggested to use these features for tracking the motion, detecting the position and inferring or decohering the the quantum state of isolated Rydberg impurities. Here we numerically model this scenario using Gross-Pitaevskii and truncated Wigner theory. Our focus is on the cumulative effect of multiple sequential Rydberg excitations on the same condensate and the local heating dynamics. We also investigate the impact of details in the electron-atom interaction potential, such as the rapid radial modulation, which is important for the condensate response within the Rydberg orbit but is less relevant for subsequent density waves outside the Rydberg excitation region.

Q 13.24 Wed 16:30 P

Collisions of solitary waves in condensates beyond mean-field theory — •Aparna Sreedharan[1], S Choudhury[1], R Mukherjee[1,2], A Streltsov[3,4], and S Wüster[1] — [1]Department of Physics, IISER Bhopal, Madhya Pradesh 462066, India — [2]Department of Physics, Imperial College, SW7 2AZ, London, UK — [3]Theoretische Chemie, Physikalisch-Chemisches Institut, Universität Heidelberg, Germany — [4]SAP Deep Learning Center of Excellence and Machine Learning Research SAP SE, Germany

A soliton is a self-reinforcing wave packet that maintains its shape despite dispersion, and appears in a large number of natural nonlinear systems including BEC. Solitons with a density maximum are referred to as bright solitons and those in BEC are composed of hundreds or thousands of identical atoms held together by their weak contact interactions. They behave very much like a compound object, with behaviour dictated by the nonlinear wave equation describing the mean field of their many body wave function. Soliton interactions in BEC are strongly affected by condensate fragmentation dynamics which we study using the TWA and MCTDHB. We also show that separate solitary waves decohere due to phase diffusion that depends on their effective ambient temperature, after which their initial mean-field relative phases are no longer well defined or relevant for collisions. In this situation, collisions are predominantly repulsive and can no longer be described within mean-field theory. Using different quantum many body techniques, we present a unified view on soliton fragmentation, phase diffusion and entanglement in their collision dynamics.

Q 13.25 Wed 16:30 P

All-Optical Matter-Wave Lens for Atom Interferometry — •Henning Albers[1], Alexander Herbst[1], Ersnt M. Rasel[1], Dennis Schlippert[1], and The Primus-Team[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]ZARM, Universität Bremen

The instability of quantum based inertial sensors highly depends on the center-of-mass motion and the expansion rate of the atomic ensemble. Precise control of these degrees of freedom is essential to perform accurate measurements of inertial effects, such as rotations or accelerations. Using time-averaged potentials in a 2μm crossed dipole trap we realize an all optical matter-wave lens which can be applied at all stages of the evaporative cooling process. By rapid decompression of the trap confinement we induce size oscillations of the trapped ensemble. Turning off the trap at a turning point of this oscillation results in a reduced velocity spread of the atomic cloud and thus a lowered expansion rate. We are able to reduce the transverse expansion temperature of ensembles containing 4×10^5 atoms from 40nK down to 3nK. The current limitations as well as the perspective to lens in transversal and longitudinal direction will be discussed.

Q 13.26 Wed 16:30 P

Quantum gas microscopy of Rydberg macrodimers — •Kritsana Srakaew[1], Simon Hollerith[1], David Wei[1], Daniel Adler[1], Antoni Rubio-Abadal[2], Andreas Kruckenhauser[3], Valentin Walther[4], Christian Gross[5], Immanuel Bloch[1,6], and Johannes Zeiher[1] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]The Institute of Photonic Sciences Mediterranean Technology, Castelldefels, Spain — [3]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria — [4]ITAMP, Harvard-Smithsonian Center of Astrophysics, Campridge, USA — [5]Physikalisches Institut, Eberhard Karls Universität, Tübingen, Germany — [6]Ludwig-Maximilians-Universität, Fakultät für Physik, München, Germany

A precise study of molecules is difficult due to a large number of motional degrees of freedom and the presence of an internal quantization axis, the interatomic axis. In the field of quantum simulation, Rydberg atoms recently gained attention due to their large interactions. These interactions also give rise to molecules with bond lengths reaching the micron scale, so-called macrodimers. Their large size allows one to pin atom pairs at a fixed orientation and distance matching the molecular bond length before photoassociation, which gives direct access to the molecular axis. Precise control and exploiting Quantum gas microscopy enables access to study different molecular symmetries and electronic structure tomography of the molecular state.

Q 13.27 Wed 16:30 P

Atomic MOT from a buffergas beam source — •Simon Hofsäss[1], Sid Wright[1], Sebastian Kray[1], Maximilian Doppelbauer[1], Eduardo Padilla[1], Boris Sartakov[2], Jesús Pérez Ríos[1], Gerard Meijer[1], and Stefan Truppe[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Prokhorov General Physics Institute, Russian Academy of Sciences, Moscow, Russia

A sample of cold atoms is the starting point of many applications in atomic and molecular physics. When trapping atoms from a hot background gas or oven source into a magneto optical trap (MOT), the loading time is usually on the order of seconds and limits the repetition rate of such experiments. Using our pulsed buffer gas beam source - originally designed for the production of diatomic molecules such as Aluminium monofluoride - we can load the MOT with 10^8 Cadmium atoms in less than 10ms. We trap the atoms using the $^1P_1 \leftarrow ^1S_0$ transition at 229nm using light from a frequency-quadrupled Ti:sapphire laser.

Q 14: Ultracold atoms, ions, and BEC II / Ultracold plasmas and Rydberg systems (joint session A/Q)

Time: Thursday 10:45–12:15 Location: H1

Invited Talk Q 14.1 Thu 10:45 H1

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.

Invited Talk Q 14.2 Thu 11:15 H1

Ultracold polar ^{23}Na^{39}K ground-state molecules — •Kai Konrad Voges[1], Philipp Gersema[1], Mara Meyer zum Alten Borgloh[1], Torsten Hartmann[1], Torben Alexander Schulze[1], Leon Karpa[1], Alessandro Zenesini[1,2], and Silke Ospelkaus[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]INO-CNR BEC Center and Dipartimento di Fisica, Universit 'a di Trento, 38123 Povo, Italy

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

In this talk we present the coherent creation of the light weight bosonic ^{23}Na^{39}K rovibrational ground state molecules by utilizing Feshbach molecule association and subsequent stimulated Raman adiabatic passage (STIRAP) to the ground state. We are able to create rovibrational ground-state ensembles in a single hyperfine state either as a pure ensemble or in a mixture with ultracold atoms. By applying external electric fields we induce electric molecular dipole moments of up to 1 Debye. We further present our investigations of collisional properties of the molecule-atom mixtures and the pure molecular ensemble. For the latter one we investigate the formation of long-lived sticky complexes and their light excitation by the optical dipole trap. Our measurements put a lower bound on the complex lifetime which is observed to be much larger than predicted by theoretical calculations base on RRKM theory.

Invited Talk Q 14.3 Thu 11:45 H1

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 15: General Assembly of the Quantum Optics and Photonics Division

Time: Thursday 13:00–14:00 Location: MVQ

General Assembly

Q 16: Quantum Optics

Time: Thursday 16:30–18:30 Location: P

Q 16.1 Thu 16:30 P

Incoherent seeding of a nonlinear interferometer — •Joshua Hennig[1,2], Björn Haase[1,2], Mirco Kutas[1,2], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Center for Materials Characterization and Testing, Fraunhofer ITWM, Kaiserslautern, Germany — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), Germany

Quantum sensing and imaging with undetected photons based on nonlinear interferometry has been demonstrated in various spectral regions in the past few years. Due to their low photon energy in the terahertz frequency range thermal photons contribute to the signal at room temperature. In order to investigate the effect of such incoherent photons on a nonlinear interferometer, we use an incoherent seed on a Mach-Zehnder approach based on [1]. Here, spontaneous parametric down conversion of two nonlinear crystals pumped by a 532 nm laser leads to correlated pairs of signal and idler photons at wavelengths of 810 nm and 1550 nm, respectively. While the idler photons interact with an object, only the signal photons, which then carry the object's information, are detected with a scientific CMOS camera. That way, the information can be transferred from one wavelength to another. By seeding the idler of this experiment incoherently at 1550 nm, we find that the detected count rate can be increased by at least an order of magnitude while the visibility of the interference reaches up to 90% compared to about 70% without seeding. This can be beneficial in applications with low count rates or where detectors are sparse.

[1] Lemos et al., Nature 512(7515), 409-412 (2014)

Q 16.2 Thu 16:30 P

Integrated free-space cavity optomechanics with AlGaAs heterostructures — •Anastasiia Ciers[1], Sushanth Kini Manjeshwar[1], Jamie M. Fitzgerald[2], Shu Min Wang[1], Philippe Tassin[2], and Witlef Wieczorek[1] — [1]Department of Microtechnology and Nanoscience, Chalmers University of Technology, 41258 Gothenburg, Sweden — [2]Department of Physics, Chalmers University of Technology, 41258 Gothenburg, Sweden

Cavity optomechanics exploit the coupling of mechanical resonators to light fields with applications in quantum-enhanced sensing, quantum networks, or for foundational studies. Multielement systems, whereby multiple mechanical resonators couple to the common light field, may allow reaching the single-photon strong coupling regime and open a path to explore collective effects such as synchronization or entanglement generation between mechanical resonators. Realization of these experiments is challenging due to the prerequisite of extremely precise positioning of highly reflective mechanical resonators within the cavity. In our work we address this challenge and fabricate and characterize suspended single- and bi-layer photonic crystal membranes in AlGaAs heterostructures, which simultaneously integrate a highly reflective distributed Bragg reflector. Our approach allows to create integrated, closely spaced membrane systems embedded in an optical microcavity. With proper design such systems can exhibit photonic bound states in the continuum, which can further increase the light-matter interaction. Our work paves the way for a versatile optomechanics platform realizing multielement mechanical resonators in high-Finesse microcavities.

Q 16.3 Thu 16:30 P

Nano-Macro Transition of NV centers' Optical Properties in Nanodiamond Agglomerates — •Jonas Gutsche, Ashkan Zand, Marek Bültel, and Artur Widera — Department of Physics, University of Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern

Color centers in diamond have developed to a fundamental building block of recent quantum technology as a single-photon source or optical quantum probe of magnetic fields. However, when such devices are ever further miniaturized, the host crystal of color centers decreases, leading to nanoscale effects. One of these nanoscale effects is the transition of the fluorescence lifetime towards higher timescales due to a change in the local density of states (DOS).

We present a systematic fluorescence lifetime study on different agglomeration states of nanodiamonds containing nitrogen-vacancy (NV) centers. The results reveal a heuristic transition on a length scale of approximately 1.8 μm, being in the order of three wavelengths of the NV center's emission. A simple theoretical model is employed to explain this transition due to a change of the DOS stemming from the nanodiamonds nearby and affecting the local refractive index. We find good agreement between measurement and theoretical prediction, taking the surrounding medium within 130 nm to 300 nm to calculate the local refractive index. This length scale of a quarter emission wavelength defines a transition between the nano- and macroscopic scale for optical properties.

Q 16.4 Thu 16:30 P

Collective emission of nitrogen-vacancy centers in nanodiamond agglomerates — •Ashkan Zand, Jonas Gutsche, Marek Bültel, and Artur Widera — Technische Universität Kaiserslautern und Landesforschungszentrum OPTIMAS, 67663 Kaiserslautern, Germany

Individual quantum emitters form a fundamental building block in emerging quantum technology. Collective effects, such as superradiance in ensembles of emitters, might improve the performance of such applications even further. In the transition to larger scales, however, correlations of collective systems might be covered in the environmental background.

We will present the experimental observation of Dicke-superradiance of nitrogen-vacancy (NV) centers in highly-doped nanodiamond agglomerates. Fluorescence-lifetime measurements show results consistent with increased collective effects in larger agglomerates. By contrast, the second-order correlation function fails to quantify collective effects for the case of an ensemble of collectively contributing domains to the emission. Therefore, a new figure of merit to trace and quantify collective emission based on the fluctuation statistics of the emitted light is introduced. Analyzing the quantity, we reveal increased collective effects of large diamond agglomerates.

While the experimental data originates from NV centers in diamond, the theoretical model presented here applies to a variety of other emitters such as other color centers or quantum dots, shedding light on collective effects in scalable quantum systems.

Q 16.5 Thu 16:30 P

Analyzing fluorescence lifetime of NV center in nanodiamonds using a phasor approach — •Elnaz Bazzazi, Jonas Gutsche, Ashkan Zand, and Artur Widera — Technische Universitüat Kaiserslautern und Landesforschungszentrum OPTIMAS, 67663 Kaiserslautern, Germany

The nitrogen-vacancy (NV) center in diamond has been object of intense research in quantum technology, for instance, sensing quantum information. Examining their photoluminescence in a varying environment allows engineering, controling, and detecting quantum properties of the NVs. A standard observable to sense the quantum optical properties of NVs is the fluorescence lifetime.

Here, we compare two methods used to analyze fluorescence lifetime data from highly-doped nanodiamonds. Traditionally, the data obtained by time-domain measurements from single-photon-counting modules, for example, is evaluated based on non-linear fitting. This requires choosing an appropriate model and fit function which is not always evident. Alternatively, one can consider a phasor analysis as a fit-free method employing the Fourier transform of time-domain data. We outline the principle equivalence and practical difference of both methods on data taken for lifetime measurements with pronounced non-exponential decay.

Q 16.6 Thu 16:30 P

Observation of a non-Hermitian phase transition and response dynamics in an optical quantum gas — •Aleksandr Sazhin[1], Fahri Emre Öztürk[1], Göran Hellmann[1], Jan Klaers[2], Frank Vewinger[1], Tim Lappe[1], Johann Kroha[1], Vladimir

Gladilin[3], Michiel Wouters[3], Julian Schmitt[1], and Martin Weitz[1] — [1]Universität Bonn — [2]University of Twente — [3]Universiteit Antwerpen

Quantum gases of light, such as photon or polariton condensates in optical microcavities, are collective quantum systems enabling a tailoring of dissipation from, for example, cavity loss. This gives access to new system states and phases, which would not be accessible otherwise. We experimentally demonstrate a non-Hermitian phase transition of a photon Bose-Einstein condensate to a dissipative phase characterized by a biexponential decay of the condensate's second-order coherence[1]. Although Bose-Einstein condensation is usually connected to lasing by a smooth crossover, the observed phase transition separates the biexponential phase from both lasing and an intermediate, oscillatory condensate regime. In more recent experiments, we study the response dynamics of the photon Bose-Einstein condensate to an external perturbation of the condensate photon number. Depending on the perturbation strength, we identify linear and nonlinear relaxation behavior, which we compare to the (intrinsic) second-order correlations. Our approach can be used to study a wide class of dissipative quantum phases in topological or lattice systems. [1]Oeztuerk et al., Science 372 (6537), 88 (2021)

Q 16.7 Thu 16:30 P

Rydberg quantum optics in an ultracold Rubidium gas — •Nina Stiesdal[1,2], Hannes Busche[1], Alireza Aghababaie[1], Lukas Alheit[1], Cedric Wind[1], and Sebastian Hofferberth[1] — [1]Institute für Angewandte Physik, University of Bonn — [2]Institute for Physics, Chemistry and Pharmacy, University of Southern 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. This has recently allowed us to realize a multi-photon subtractor, which we present here.

Q 16.8 Thu 16:30 P

Composite pulses for nitrogen-vacancy colour centres — Josselin Bernardoff, •Jan Thieme, Ricky-Joe Plate, Manika Bhardwaj, Markus Debatin, and Kilian Singer — Universität Kassel, Kassel, Deutschland

We present numerical and preliminary experimental results of the application of tailored composite pulses [1] to shape the excitation profile addressing only selected quantum states in the system. By using analytical methods applied to the Rosen-Zener excitation model [2], we derive excitation profiles for a broadband excitation profile with respect to detuning and pulse duration. Towards this goal we are using an arbitrary waveform generator to supply these pulses to single nitrogen-vacancy colour centres. As an outlook we will show how the derived pulse sequences can be extended to qubit manipulation in trapped ions.

[1] B. T. Torosov and N. V. Vitanov, Phys. Rev. A 83, 053420 (2011). [2] N. Rosen and C. Zener, Phys. Rev. 40, 502 (1932).

Q 16.9 Thu 16:30 P

Microwave Driving of Dipole-Forbidden Transitions in the Electronic Ground State of the NV Center — •Florian Böhm[1], Niko Nikolay[1], Sascha Neinert[1], Christoph Nebel[2], and Oliver Benson[1] — [1]Institut für Physik & IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]Nanomaterials Research Institute, Kanazawa University, Japan

The nitrogen-vacancy (NV) center in diamond is one of the most widely studied solid-state spin systems, as it can be used in a wide variety of quantum applications [1]. It features an electronic qutrit ground state with long coherence times, which can be coherently controlled at room temperature by microwave pulses. The broad range of possible applications the NV center offers stimulates a great interest in developing new control schemes or adapting control schemes to the NV center.

For this reason, we investigate the application of two-photon microwave pulses to a single NV center, in order to directly drive the spin-forbidden transition between the $m_S = -1 \leftrightarrow m_S = +1$ sublevels. More precisely, we show the experimental implementation of two different two-photon schemes, stimulated Raman transitions (SRT) and stimulated Raman adiabatic passage (STIRAP) [2]. We show, that both schemes can successfully drive the dipole-forbidden transition and compare the experimental results to numerical simulations. Furthermore, we compare both schemes on their robustness and success of the spin-swap, as well as their experimental challenges.

[1] Doherty, Marcus W., et al., Physics Reports 528.1 (2013): 1-45
[2] Böhm, Florian, et al., Phys. Rev. B, 104.3 (2021): 035201

Q 16.10 Thu 16:30 P

Rydberg quantum optics in ultracold Ytterbium gases — •Thilina Muthu-arachchige, Rafael R. Paiva, Jiachen Zhao, Mohammad Noaman, and Sebastian Hofferberth — Institut for Applied Physics, University of Bonn, Wegelerstraße 8, 53115, Bonn

Rydberg systems offer exciting prospects for future all optical quantum computing due to the large scaling and also for investigation of exotic many-body quantum states of light. Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons. In our group, we explore this novel approach in multiple experimental setups.

Here we present the 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. Towards this goal, Yb offers several advantages compared to alkali atoms; such as long coherence times, long Rayleigh length, simple energy level scheme and efficient cooling transitions. We discuss details of our experimental setup and report on the progress towards observation of few-photon nonlinearities in Yb.

Q 16.11 Thu 16:30 P

High-harmonic generation in Fibonacci quasicrystals — •Francisco Navarrete and Dieter Bauer — Institut für Physik, Universität Rostock, 18051 Rostock, Deutschland

The mechanism of high-harmonic generation (HHG) in solids has been theoretically studied over recent years, and experimentally verified a decade ago. While many conclusions have been drawn for this process in periodic crystals, it has also been predicted a strong dependence of the HHG spectrum on the topology of the sample. The latter motivated us to explore the strong-field response of quasicrystals (QCs), which are solids whose atoms are geometrically placed in ways that are symmetrically forbidden in periodic crystals (which are comparatively abundant and have been vastly studied). This might provide insight on fundamental questions of its electron dynamics and allow us to explore the suitability to use them for compact short-wavelength light sources. Even though in our study we focus on a simplified model for QCs, the Fibonacci chain, these conclusions might also be extrapolated to both synthesized and natural QCs.

Q 16.12 Thu 16:30 P

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, Isabell Imwalle, Baptist Piest, Maike Lachmann, Johnas Böhm, and Ernst M. Rasel — Institut für Quantenoptik, Hannover, Deutschland

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 17: Quantum Effects

Time: Thursday 16:30–18:30 Location: P

Q 17.1 Thu 16:30 P

Inverse design of artificial two-level systems with Mössbauer nuclei in thin-film cavities — •Oliver Diekmann, Dominik Lentrodt, and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

We theoretically investigate the platform of Mössbauer nuclei in thin-film cavities for applications in x-ray quantum optics. Thin-film cavities are stacks of layers of different materials. One or several of the layers consist of a Mössbauer isotope (typically Fe57), i.e. the nuclei within this layer have a spectrally very narrow nuclear transition. At low probing intensities, the nuclei-cavity system is equivalent to a quantum few-level scheme, e.g. a single, thin layer of Mössbauer nuclei in the cavity forms an artificial two-level system (TLS) whose transition frequency and decay constant we can tune by e.g. modifying the surrounding cavity. The capabilities of the platform have already been hinted in a number of experiments.

While it is possible to ab initio calculate the quantum optical system simulated by a cavity structure, the inverse problem of finding the cavity structure to realize a desired level scheme is an open problem. Using a quantum optical framework based on the electromagnetic Green function, we could recently solve this problem for the TLS case, and determined its full tuning capabilities while taking into account practical considerations. The approach will also allow for extensions to multi-level schemes, otherwise inaccessible at hard x-ray energies, and, thus, promises to further the field of x-ray quantum optics towards applications in spectroscopy and x-ray based quantum technologies.

Q 17.2 Thu 16:30 P

Open Quantum Systems Approach to Photonic Bose-Einstein Condensation — •Andris Erglis[1] and Stefan Yoshi Buhmann[2] — [1]University of Freiburg, Germany — [2]University of Kassel, Germany

The photonic Bose-Einstein condensate is a recently observed collective ground state of a coupled light-matter system. We describe this novel quantum state on the basis of macroscopic quantum electrodynamics in dispersing and absorbing environments. To describe the coupled photon-dye dynamics dynamics, we derive a master equation using Nested Open Quantum Systems approach with all the necessary parameters to describe the condensation process. This approach allows us to describe the photon condensate in arbitrary geometries because all the decay constants can be expressed in terms of Green's tensor.

In the first step we derive constants responsible for spontaneous and cavity decay and laser pumping by tracing out the respective photon field baths. In the second step we trace out the rovibrational modes of the molecules as an effective bath which are influenced by dissipation constants derived in the first step. From that we derive the cavity mode absorption and emission rates of the dye molecules.

Q 17.3 Thu 16:30 P

Photon-number entanglement generated by sequential excitation of a two-level atom — Stephen C Wein[1], Juan Carlos Loredo[2], Maria Maffei[3], Paul Hilaire[2], Abdelmounaim Harouri[2], Niccolo Somaschi[4], Aristide Lemaitre[2], Isabel Sagnes[2], Loic Lanco[2,5], Olivier Krebs[2], Alexia Auffeves[3], Christoph Simon[1], Pascale Senellart[2], and •Carlos Anton-Solanas[2,6] — [1]University of Calgary, Canada — [2]C2N-CNRS, France — [3]Institut Néel-CNRS France — [4]Quandela SAS, France — [5]Univ. Paris Diderot, France — [6]Carl von Ossietzky Univ., Germany

During the spontaneous emission of light from an excited two-level atom, the atom briefly becomes entangled with the photonic field, producing the entangled state $\alpha|e,0\rangle + \beta|g,1\rangle$, where g and e are the ground and excited states of the atom, and 0 and 1 are the vacuum and single photon states. We experimentally show that the spontaneous emission can be used to deliver on demand photon-number entanglement encoded in time. By exciting a charged quantum dot (an artificial two-level atom) with two sequential π pulses, we generate a photon-number Bell state $\alpha|00\rangle + \beta|11\rangle$. We characterize the quantum properties of this state using time-resolved photon correlation measurements. We theoretically show that applying longer sequences of π pulses to a two-level atom can produce multipartite time-entangled states with properties linked to the Fibonacci sequence. Our results show that spontaneous emission is a powerful entanglement resource and it can be further exploited to generate new quantum photonic states (multipartite and also high-dimensional entangled states.

Q 17.4 Thu 16:30 P

Superradiant emission of an atomic beam into an optical cavity — •Simon B. Jäger, Haonan Liu, John Cooper, and Murray J. Holland — JILA, National Institute of Standards and Technology, and University of Colorado, Boulder, Colorado 80309-0440, USA

We investigate the different emission regimes of a pre-excited and collimated atomic beam traversing an optical cavity. In the regime where the cavity degrees of freedom can be adiabatically eliminated, we find that the atoms undergo superradiant emission when the collective linewidth exceeds transit-time, homogeneous, and inhomogeneous broadening mechanisms. In this regime we find a superradiant phase where the atomic beam undergoes continuous monochromatic light emission. We analyze the stability of the emission frequency with respect to homogeneous and inhomogeneous frequency shifts and predict the emergence of dynamical superradiant phases where the emission spectrum shows several frequency components.

Q 17.5 Thu 16:30 P

Classifying and harnessing multi-mode light-matter interaction in lossy resonators — •Dominik Lentrodt[1], Oliver Diekmann[1], Christoph H. Keitel[1], Stefan Rotter[2], and Jörg Evers[1] — [1]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg — [2]Institute for Theoretical Physics, Vienna University of Technology (TU Wien), 1040 Vienna, Austria

In this contribution, we present a practical framework to characterize multi-mode effects on quantum systems coupled to lossy resonators. By relating recently developed quantum optical few-mode models [1, 2] to the Mittag-Leffler pole expansion [3] of the cavity's classical Green's function, we identify three distinct classes of multi-mode effects in the loss-dominated regime. We show that these effects are crucial for understanding spectroscopic signatures in leaky and absorptive resonators, and that they further provide a tuning knob to design artificial quantum systems through such environments. Both aspects are illustrated with applications in x-ray cavity QED with Mössbauer nuclei [4, 5].

[1] D. Lentrodt and J. Evers, *PRX* **10**, 011008 (2020)
[2] I. Medina et al. *PRL* **126**, 093601 (2021)
[3] P. Lalanne et al. *Laser & Photonics Reviews* **12**, 1700113 (2018)
[4] R. Röhlsberger and J. Evers, *Quantum optical phenomena in nuclear resonant scattering*, in "Modern Mössbauer Spectroscopy", edited by Y. Yoshida and G. Langouche (2021)
[5] D. Lentrodt, K. P. Heeg, C. H. Keitel, and J. Evers, *PRResearch* **2**, 023396 (2020)

Q 17.6 Thu 16:30 P

Spatio-temporal control of correlations with non-local dissipation — Kushal Seetharam[4], Alessio Lerose[3], Rosario Fazio[2], and •Jamir Marino[1] — [1]jamirmarino@gmail.com — [2]fazio@ictp.it — [3]alerose@sissa.it — [4]kis@mit.edu

[I am applying for a contributed talk]

Controlling the spread of correlations in quantum many-body systems is a key challenge at the heart of quantum science and technology. Correlations are usually destroyed by dissipation arising from coupling between a system and its environment. Here, we show that dissipation can instead be used to engineer a wide variety of spatio-temporal correlation profiles in an easily tunable manner. We describe how dissipation with any translationally-invariant spatial profile can be realized in cold atoms trapped in an optical cavity. A uniform external field and the choice of spatial profile can be used to design when and how dissipation creates or destroys correlations. We demonstrate this control by preferentially generating entanglement at a desired wavevector. We thus establish non-local dissipation as a new route towards engineering the far-from-equilibrium dynamics of quantum information, with potential applications in quantum metrology, state preparation, and transport.

Q 17.7 Thu 16:30 P

Towards a coherent spin photon interface for quantum repeaters using NV centers in diamond — •Maximilian Pallmann[1], Jeremias Resch[1], Jonathan Körber[3], Julia Heupel[2], Cyril Popov[2], Rainer Stöhr[3], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Kassel — [3]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 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%. We present a spatially resolved characterization of a coupled cavity-membrane device and present a cryogenic cavity platform featuring sub pm mechanical noise during quiet periods.

Q 17.8 Thu 16:30 P

Phonon pair creation by tearing apart quantum vacuum fluctuations — •Florian Hasse[1], Robin Thomm[1], Deviprasath Palani[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 17.9 Thu 16:30 P

Fully fiber coupled devices for efficient cryogenic spectroscopy of single and small ensembles of rare earth ions — Jannis Hessenauer[1], •Evgenij Vasilenko[1], Xiaoyu Cheng[1,2], Tobias Krom[1,3], Christina Ioannou[1], Christopher Hins[1], Senthil Kuppusamy[1], Mario Ruben[1], Philippe Goldner[4], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Universität Stuttgart, Stuttgart,Germany — [3]Universität Heidelberg, Heidelberg,Germany — [4]Institut de Recherche de Chimie Paris IRCP, Paris, France

Rare earth ions in solid state hosts are a prime candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. In order to achieve an efficient spin-photon interface, we try to couple single ions to a fiber-based Fabry-Pérot cavity. However, operation of these cavities at cryogenic temperatures has proven difficult, due to high demands on the mechanical stability. To tackle these challenges, we report on the development of two different, monolithic cavity assemblies, both sacrificing some lateral scanning ability in order to significantly increase the passive stability.

Characterizing the optical and spin properties of rare earth doped materials requires spectroscopic measurements of ensembles, such as spectral hole burning and photon echo spectroscopy. We report on the development of a miniaturized, fiber-coupled scheme to perform these experiments, requiring only microscopic amounts of sample and comparatively low laser power in order to see well resolved spectral hole signatures.

Q 17.10 Thu 16:30 P

Steady-state diagonalization of a dielectric medium with dispersion and dissipation — •Sascha Lang[1,2], Ralf Schützhold[1,3,2], 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 V6T 1Z1, Canada

The established Hopfield model for non-dissipative dielectrics incorporates dispersion by coupling the electric field inside a medium to a continuous set of harmonic oscillators. We further add dissipation by coupling each of these *matter oscillators* to a scalar environment field [1]. After canonical quantization, the Heisenberg equations of motions can be solved in terms of steady-state solutions which diagonalize the system Hamiltonian. Therefore, our model has a well-defined ground state, which is essential for describing quantum vacuum phenomena such as quantum radiation (e.g. photon creation from vacuum).

[1] S. Lang, R. Schützhold, W. G. Unruh, "Quantum radiation in dielectric media with dispersion and dissipation", Phys. Rev. D 102, 125020 (2020)

Q 17.11 Thu 16:30 P

Optical Signatures of Quantum Vacuum Nonlinearities in the Strong Field Regime — •Leonhard Klar[1,2], Holger Gies[1,2], and Felix Karbstein[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.

As an example, we study the collision of up to four optical laser pulses and pay attention to sum and difference frequency generation. We demonstrate how this information can be used to enhance the signal photon yield in laser pulse collisions for a given total laser energy.

Q 17.12 Thu 16:30 P

X-ray vacuum diffraction at finite spatio-temporal offset — •Ricardo Oude Weernink[1,2,3] and Felix Karbstein[1,2,3] — [1]Helmholtz-Institut Jena, Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [3]Theoretisch-Physikalisches Institut, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Jena, Germany

Quantum electrodynamics predicts effective non-linear interactions mediated by the quantum vacuum between applied strong electromagnetic fields. One prominent signature of these non-linear interactions is photon-photon scattering. Measuring this process experimentally using macroscopic fields is a difficult endeavour and has yet to be achieved. In such high-intensity laser experiments separating the signal from the relatively large background poses a major challenge. Our research focuses on finding the optimal combination of beam positioning, laser modes and parameters.

In this poster we study the nonlinear QED signature of x-ray vacuum diffraction in the head-on collision of optical high-intensity and x-ray free-electron laser pulses at finite spatio-temporal offsets between the laser foci. To this end, we model both the pump and probe fields as pulsed paraxial Gaussian beams and analyze this effect from first principles. We focus on vacuum diffraction both as an individual signature of quantum vacuum nonlinearity and as a potential means to improve the signal-to-background-separation in vacuum birefringence experiments. Our work is relevant for ongoing and projected experiments at SACLA (Japan) and the European XFEL (Germany).

Q 17.13 Thu 16:30 P

Strong interaction between free electrons and high-Q whispering gallery modes — •Jan-Wilke Henke[1,2], Arslan S. Raja[3], Armin Feist[1,2], Guanhao Huang[3], Germaine Arend[1,2], Yujia Yang[3], F. Jasmin Kappert[1,2], Rui Ning Wang[3], Marcel Möller[1,2], Jiahe Pan[3], Junqiu Liu[3], Ofer Kfir[1,2], Tobias J. Kippenberg[3], and Claus Ropers[1,2] — [1]Max Planck Institute for

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Achieving strong coupling of electron beams with single photons promises advancements in quantum optics with free electrons and will enable observation of effects like cavity photon-mediated electron-electron entanglement.

Here, we demonstrate the interaction of a free-electron beam with a single, continuous wave-pumped optical mode of a chip-based silicon nitride microresonator [1]. Employing resonant enhancement, which allows for achieving unity electron-photon scattering efficiency at unprecedentedly low optical pump powers, we observe electron-light phase matching of the interaction. Finally, we discuss the prospect of electron-mediated photon generation and entanglement.

This combination of integrated photonics with electron microscopy enables tailoring of the electron-light interaction, which paves the way to experiments in the strong-coupling regime.

[1] J.-W. Henke, A. S. Raja, et al., preprint, arXiv:2105.03729 (2021)

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Nonlinear optics at the single photon level with an organic molecule — •André Pscherer[1], Manuel Meierhofer[1], Daqing Wang[1], Hrishikesh Kelkar[1], Diego Martín-Cano[1], Tobias Utikal[1], Stephan Götzinger[2,1,3], and Vahid Sandghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany — [3]Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany

Nonlinear light-matter interactions usually involve macroscopic materials and high intensities, often involving pulsed lasers. Here, we show that a single organic molecule embedded in a solid matrix can strongly couple to a high-finesse Fabry-Pérot cavity to mediate nonlinear interactions at the level of single photons. We demonstrate vacuum Rabi oscillations, single-photon switching, photon number sorting and four-wave mixing [1].

[1] A. Pscherer, *et al.*, arXiv:2105.02560 (2021)