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

Christiane Koch
Freie Universität Berlin
Fachbereich Physik
Arnimallee 14
14195 Berlin
christiane.koch@fu-berlin.de

Overview of Invited Talks and Sessions

(Lecture halls HS 1015, 1199, 1221, 3118, 3219, and Aula; Poster Tent B, KG I Foyer, and Aula Foyer)

Invited Talks

Q 5.1	Mon	11:00–11:30	HS 1221	**Tailoring design of quantum sensor to biomedical applications** — •Victor Lebedev, Simon Nordenstroem, Stefan Hartwig, Thomas Middelmann
Q 10.1	Mon	17:00–17:30	HS 1199	**Correlated light-matter states from first principles and their use for chirality, and chemistry** — •Christian Schäfer
Q 15.1	Tue	11:00–11:30	HS 1015	**Levitated nanoparticles as testbeds for fundamental aspects of physics** — •Julen S. Pedernales
Q 18.1	Tue	11:00–11:30	HS 1221	**Continuous lasing and pinning of the dressed cavity resonance with strongly-coupled ^{88}Sr atoms in a ring cavity** — •Vera Schäfer
Q 26.1	Wed	11:00–11:30	HS 1015	**Ultracold interactions between ions and polar molecules** — •Leon Karpa
Q 26.6	Wed	12:30–13:00	HS 1015	**Quantum Logic Spectroscopy of the Hydrogen Molecular Ion** — David Holzapfel, Fabian Schmid, Nick Schwegler, Oliver Stadler, Martin Stadler, Jonathan Home, •Daniel Kienzler
Q 27.1	Wed	11:00–11:30	Aula	**Engineering of many-body states in a driven-dissipative cavity QED system** — Rodrigo Rosa-Medina, Fabian Finger, Nicola Reiter, Jakob Fricke, Panagiotis Christodoulou, Davide Dreon, Alexander Baumgärtner, Simon Hertlein, Justyna Stefaniak, David Baur, Dalila Rivero, Gabriele Natale, Tilman Esslinger, •Tobias Donner
Q 34.1	Wed	14:30–15:00	HS 1221	**Optically addressable nuclear spin registers with V2 center in 4H-SiC** — •Vadim Vorobev
Q 35.1	Wed	14:30–15:00	HS 3118	**Quantum correlations in the phase space** — Martin Bohmann, Jan Sperling, Nicola Biagi, Alessandro Zavatta, Marco Bellini, •Elizabeth Agudelo
Q 42.1	Thu	11:00–11:30	HS 1015	**Theory of robust quantum many-body scars in long-range interacting systems** — •Silvia Pappalardi
Q 45.1	Thu	11:00–11:30	HS 1221	**Quantum Sensing in Space for Fundamental Physics and Applications** — •Naceur Gaaloul
Q 51.1	Thu	14:30–15:00	HS 1199	**From the origin of antibunching to novel quantum light sources based on two-photon interference** — •Martin Cordier, Luke Masters, Gabriele Maron, Xin-Xin Hu, Lucas Pache, Philipp Schneeweiss, Max Schemmer, Jürgen Volz, Arno Rauschenbeutel
Q 52.1	Thu	14:30–15:00	HS 1221	**Structured light and its interaction with matter** — •Robert Fickler, Rafael Barros, Lea Kopf, Marco Ornigotti
Q 61.1	Fri	11:00–11:30	HS 1199	**Photonic integration for trapped-ion quantum metrology** — •Elena Jordan, Guochun Du, Carl-Frederik Grimpe, Fatemeh Salahshoori, Markus Kromrey, Atasi Chatterjee, Anastasiia Sorokina, Steffen Sauer, Anton Peshkov, Gillenhaal Beck, Karan Mehta, Stefanie Kroker, Andrey Surzhykov, Tanja Mehlstäubler
Q 67.1	Fri	14:30–15:00	Aula	**Towards an Artificial Muse for new Ideas in Quantum Physics** — •Mario Krenn

Invited Talks of the joint Symposium SAMOP Dissertation Prize 2024 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Mon	14:30–15:00	Paulussaal	**Quantum steering of a Szilárd engine** — •Konstantin Beyer
SYAD 1.2	Mon	15:00–15:30	Paulussaal	**Does a disordered Heisenberg quantum spin system thermalize?** — •Titus Franz
SYAD 1.3	Mon	15:30–16:00	Paulussaal	**Quantum optical few-mode models for lossy resonators** — •Dominik Lentrodt
SYAD 1.4	Mon	16:00–16:30	Paulussaal	**Non-Hermitian topology and directional amplification** — •Clara Wanjura

Prize Talks of the joint Awards Symposium (SYAS)

See SYAS for the full program of the symposium.

SYAS 1.1	Tue	15:00–15:30	Paulussaal	**Quantum Simulations with Atoms, Molecules and Photons** — •Immanuel Bloch
SYAS 1.2	Tue	15:30–16:00	Paulussaal	**Spectroscopy of molecules with large amplitude motions: a journey from molecular structure to astrophysics.** — •Isabelle Kleiner
SYAS 1.3	Tue	16:00–16:30	Paulussaal	**Quantum x-ray nuclear optics: progress and prospects** — •Olga Kocharovskaya
SYAS 1.4	Tue	16:30–17:00	Paulussaal	**3D printed complex microoptics: fundamentals and first benchmark applications** — •Harald Giessen

Invited Talks of the joint Symposium Controlled Molecular Collisions (SYCC)

See SYCC for the full program of the symposium.

SYCC 1.1	Wed	11:00–11:30	Paulussaal	**Dynamics of CO_2 activation by transition metal ions - The importance of intersystem crossing** — •Jennifer Meyer
SYCC 1.2	Wed	11:30–12:00	Paulussaal	**Angular momentum of small molecules: quasiparticles and topology** — •Mikhail Lemeshko
SYCC 1.3	Wed	12:00–12:30	Paulussaal	**Manoeuvring chemical reactions one degree of freedom at a time** — •Jutta Toscano
SYCC 1.4	Wed	12:30–13:00	Paulussaal	**Cold and controlled collisions using tamed molecular beams** — •Sebastiaan van de Meerakker

Invited Talks of the joint Symposium Ultrafast Quantum Nano-Optics (SYQO)

See SYQO for the full program of the symposium.

SYQO 1.1	Fri	11:00–11:30	Paulussaal	**Coherent and incoherent dynamics of colloidal plexcitonic nanohybrids** — •Elisabetta Collini
SYQO 1.2	Fri	11:30–12:00	Paulussaal	**Dissipative Many-Body Dynamics in Atomic Subwavelength Arrays in Free Space** — •Stefan Ostermann
SYQO 1.3	Fri	12:00–12:30	Paulussaal	**Quantum dot sources: efficiency, entanglement, and correlations.** — •Ana Predojević
SYQO 1.4	Fri	12:30–12:45	Paulussaal	**Compact chirped fiber Bragg gratings for single-photon generation from quantum dots** — •Vikas Remesh, Ria Krämer, René Schwarz, Florian Kappe, Yusuf Karli, Thomas Bracht, Saimon Covre da Silva, Armando Rastelli, Doris Reiter, Stefan Nolte, Gregor Weihs
SYQO 1.5	Fri	12:45–13:00	Paulussaal	**Observing Ultrafast Coherent Dynamics following Selective Excitation of a Single Quantum Dot** — •Darius Hashemi Kalibar, Philipp Henzler, Ron Tenne, Alfred Leitenstorfer

Sessions

Q 1.1–1.7	Mon	11:00–13:00	HS 1010	**Ultra-cold Atoms, Ions and BEC I (joint session A/Q)**
Q 2.1–2.8	Mon	11:00–13:00	HS 1015	**QED**
Q 3.1–3.8	Mon	11:00–13:00	Aula	**Bosonic Quantum Gases I (joint session Q/A)**
Q 4.1–4.8	Mon	11:00–13:00	HS 1199	**Hybrid Quantum Systems**
Q 5.1–5.7	Mon	11:00–13:00	HS 1221	**Magnetometry**
Q 6.1–6.8	Mon	11:00–13:00	HS 3118	**Solid State Quantum Optics I**
Q 7.1–7.8	Mon	11:00–13:00	HS 3219	**Quantum Communication I**
Q 8.1–8.8	Mon	17:00–19:00	HS 1010	**Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)**
Q 9.1–9.8	Mon	17:00–19:00	Aula	**Bosonic Quantum Gases II (joint session Q/A)**
Q 10.1–10.7	Mon	17:00–19:00	HS 1199	**Cavity QED**
Q 11.1–11.8	Mon	17:00–19:00	HS 1221	**Precision Measurements I (joint session Q/A)**
Q 12.1–12.8	Mon	17:00–19:00	HS 3118	**Quantum Communication II**
Q 13.1–13.8	Mon	17:00–19:00	HS 3219	**Quantum Technologies**
Q 14.1–14.8	Tue	11:00–13:00	HS 1098	**Precision Spectroscopy of Atoms and Ions I (joint session A/Q)**
Q 15.1–15.7	Tue	11:00–13:00	HS 1015	**Optomechanics**
Q 16.1–16.8	Tue	11:00–13:00	Aula	**Bosonic Quantum Gases III (joint session Q/A)**
Q 17.1–17.8	Tue	11:00–13:00	HS 1199	**Quantum Information I**
Q 18.1–18.7	Tue	11:00–13:00	HS 1221	**Trapping and Cooling of Atoms (joint session Q/A)**
Q 19.1–19.8	Tue	11:00–13:00	HS 3044	**Ultracold Molecules and Precision Spectroscopy (joint session MO/Q)**
Q 20.1–20.8	Tue	11:00–13:00	HS 3118	**Quantum Many-Body Dynamics**
Q 21.1–21.8	Tue	11:00–13:00	HS 3219	**Quantum Communication III**
Q 22	Tue	13:15–14:15	HS 1199	**Members' Assembly**
Q 23.1–23.50	Tue	17:00–19:00	Tent B	**Poster I**
Q 24.1–24.47	Tue	17:00–19:00	KG I Foyer	**Poster II**
Q 25.1–25.8	Wed	11:00–13:00	HS 1098	**Precision Spectroscopy of Atoms and Ions II (joint session A/Q)**
Q 26.1–26.6	Wed	11:00–13:00	HS 1015	**Ultracold Molecules (joint session Q/MO)**
Q 27.1–27.7	Wed	11:00–13:00	Aula	**Phase Transitions**
Q 28.1–28.8	Wed	11:00–13:00	HS 1199	**Fermionic Quantum Gases I (joint session Q/A)**
Q 29.1–29.8	Wed	11:00–13:00	HS 1221	**Photonics**
Q 30.1–30.8	Wed	11:00–13:00	HS 3118	**Color Centers I**
Q 31.1–31.8	Wed	11:00–13:00	HS 3219	**Quantum Communication IV**
Q 32.1–32.8	Wed	14:30–16:30	Aula	**Fermionic Quantum Gases II (joint session Q/A)**
Q 33.1–33.8	Wed	14:30–16:30	HS 1199	**Open Quantum Systems**
Q 34.1–34.6	Wed	14:30–16:15	HS 1221	**Color Centers II**
Q 35.1–35.7	Wed	14:30–16:30	HS 3118	**Quantum States of Light**
Q 36.1–36.8	Wed	14:30–16:30	HS 3219	**Quantum Metrology and Interference**
Q 37.1–37.59	Wed	17:00–19:00	Tent B	**Poster III**
Q 38.1–38.48	Wed	17:00–19:00	KG I Foyer	**Poster IV**
Q 39.1–39.16	Wed	17:00–19:00	Aula Foyer	**Poster V**
Q 40.1–40.8	Thu	11:00–13:00	HS 1010	**Precision Spectroscopy of Atoms and Ions III (joint session A/Q)**
Q 41.1–41.8	Thu	11:00–13:00	HS 1098	**Ultra-cold Atoms, Ions and BEC II (joint session A/Q)**
Q 42.1–42.7	Thu	11:00–13:00	HS 1015	**Long-range Interactions**
Q 43.1–43.8	Thu	11:00–13:00	Aula	**Color Centers III**
Q 44.1–44.8	Thu	11:00–13:00	HS 1199	**Quantum Information II**
Q 45.1–45.7	Thu	11:00–13:00	HS 1221	**Quantum Metrology for Fundamental Physics**
Q 46.1–46.8	Thu	11:00–13:00	HS 3118	**Lasers I**
Q 47.1–47.8	Thu	11:00–13:00	HS 3219	**Open Quantum Systems**
Q 48.1–48.8	Thu	14:30–16:30	HS 1010	**Ultra-cold Atoms, Ions and BEC III (joint session A/Q)**
Q 49.1–49.7	Thu	14:30–16:15	HS 1098	**Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)**
Q 50.1–50.8	Thu	14:30–16:30	Aula	**Quantum Gases (joint session Q/A)**
Q 51.1–51.7	Thu	14:30–16:30	HS 1199	**Quantum Optical Correlations**
Q 52.1–52.7	Thu	14:30–16:30	HS 1221	**Structured Light**
Q 53.1–53.8	Thu	14:30–16:30	HS 3118	**Quantum Control**
Q 54.1–54.8	Thu	14:30–16:30	HS 3219	**Quantum Optics in Space**

Q 55.1–55.47	Thu	17:00–19:00	Tent B	**Poster VI**
Q 56.1–56.42	Thu	17:00–19:00	KG I Foyer	**Poster VII**
Q 57.1–57.17	Thu	17:00–19:00	Aula Foyer	**Poster VIII**
Q 58.1–58.8	Fri	11:00–13:00	HS 1098	**Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)**
Q 59.1–59.8	Fri	11:00–13:00	HS 1015	**Lasers II**
Q 60.1–60.8	Fri	11:00–13:00	Aula	**Quantum Computing and Simulation I**
Q 61.1–61.7	Fri	11:00–13:00	HS 1199	**Trapped Ions (joint session Q/A)**
Q 62.1–62.8	Fri	11:00–13:00	HS 1221	**Precision Measurements II (joint session Q/A)**
Q 63.1–63.7	Fri	11:00–12:45	HS 3118	**Strong Light-Matter Interaction**
Q 64.1–64.8	Fri	11:00–13:00	HS 3219	**Solid State Quantum Optics II**
Q 65.1–65.8	Fri	14:30–16:30	HS 1010	**Ultra-cold Atoms, Ions and BEC V (joint session A/Q)**
Q 66.1–66.8	Fri	14:30–16:30	HS 1098	**Precision Spectroscopy of Atoms and Ions V / Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)**
Q 67.1–67.7	Fri	14:30–16:30	Aula	**Machine Learning**
Q 68.1–68.8	Fri	14:30–16:30	HS 1199	**Quantum Computing and Simulation II**
Q 69.1–69.8	Fri	14:30–16:30	HS 1221	**Precision Measurements III (joint session Q/A)**
Q 70.1–70.7	Fri	14:30–16:15	HS 3118	**Quantum Optics**
Q 71.1–71.8	Fri	14:30–16:30	HS 3219	**Nano-Optics**

Members' Assembly of the Quantum Optics and Photonics Division

Tuesday 13:15–14:15 HS 1199

- Bericht
- Verschiedenes

Q 1: Ultra-cold Atoms, Ions and BEC I (joint session A/Q)

Time: Monday 11:00–13:00 Location: HS 1010

Invited Talk Q 1.1 Mon 11:00 HS 1010

Exploring the Supersolid Stripe Phase in a Spin-Orbit Coupled Bose-Einstein Condensate — •Sarah Hirthe, Vasiliy Makhalov, Rémy Vatré, Craig Chisholm, Ramón Ramos, and Leticia Tarruell — ICFO - The Institute of Photonic Sciences, Castelldefels, Spain

Spin-orbit coupled Bose-Einstein condensates, where the internal state of the atoms is linked to their momentum through optical coupling, are a flexible experimental platform to engineer synthetic quantum many-body systems. In my talk, I will present recent work where we have exploited the interplay of spin-orbit coupling and tunable interactions in potassium BECs to observe and characterize the supersolid stripe phase. By optically coupling two internal states of potassium-41 using a two-photon Raman transition, we engineer a single particle dispersion relation with characteristic double-well structure. When the intrawell interactions dominate over the interwell ones, both minima are occupied and their populations interfere, leading to a system with a modulated (striped) density profile. The BEC then behaves as a supersolid: a phase that spontaneously breaks both gauge and translation symmetry, and which combines the frictionless flow of a superfluid and the crystalline structure of a solid. Using a matter-wave lensing technique, we magnify the density profile of the cloud and measure in situ the contrast and spacing of the stripes. Furthermore, we characterize the collective modes of the system and their dependence on interactions and coupling strength.

Q 1.2 Mon 11:30 HS 1010

Determination of the dissipative response of a circularly driven atomic erbium quantum Hall system — •Franz Richard Huybrechts, Arif Warsi Laskar, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn

Cold atomic gases are attractive systems for the study of topological states and phases. Here we report on experimental work studying the dissipative response of a synthetic atomic erbium quantum Hall system to two different handed modes of circular shaking. In general, the dissipative response of a topological system, expressed by its circular dichroism, is linked to the transport properties by a Kramers-Kronig relation. In our experiment, for a cold cloud of erbium atoms a quantum Hall geometry is realised in a two-dimensional state space, consisting of one spatial and one synthetic dimension, with the latter being encoded in the Zeeman quantum number of erbium atoms in the ground state. Our measurements give evidence for a difference in the excitation rates between left and right handed driving. The current status of this ongoing experiment will be reported.

Q 1.3 Mon 11:45 HS 1010

Drude weight and the many-body quantum metric in one-dimensional Bose systems — •Grazia Salerno[1], Tomoki Ozawa[2], and Päivi Törmä[1,2] — [1]Department of Applied Physics, Aalto University School of Science, FI-00076 Aalto, Finland — [2]Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Sendai 980-8577, Japan

We study the effect of quantum geometry on the many-body ground state of one-dimensional interacting bosonic systems. We find that the Drude weight is given by the sum of the kinetic energy and a term proportional to the many-body quantum metric of the ground state. Notably, the many-body quantum metric determines the upper bound of the Drude weight. We validate our results on the Creutz ladder, a flat-band model, using exact diagonalization at half and unit densities. Our work sheds light on the importance of the many-body quantum geometry in one-dimensional interacting bosonic systems.

Q 1.4 Mon 12:00 HS 1010

Shapiro steps in driven atomic Josephson junctions — •Vijay Singh[1], Juan Polo[1], Ludwig Mathey[2], and Luigi Amico[1] — [1]Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE — [2]Zentrum für Optische Quantentechnologien and Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany

We study driven atomic Josephson junctions realized by coupling two two-dimensional atomic clouds with a tunneling barrier. By moving the barrier at a constant velocity, dc and ac Josephson regimes are characterized by a zero and nonzero atomic density difference across the junction, respectively. Here, we monitor the dynamics resulting in the system when, in addition to the above constant velocity protocol, the position of the barrier is periodically driven. We demonstrate that the time-averaged particle imbalance features a step-like behavior that is the analog of Shapiro steps observed in driven superconducting Josephson junctions. The underlying dynamics reveals an intriguing interplay of the vortex and phonon excitations, where Shapiro steps are induced via suppression of vortex growth. We study the system with a classical-field dynamics method, and benchmark our findings with a driven circuit dynamics.

Q 1.5 Mon 12:15 HS 1010

Collisional dynamics between an ion and a Rydberg S-state — •Moritz Berngruber[1], Daniel Bosworth[2], Óscar Andrey Herrera Sancho[1], Viraatt Anasuri[1], Jennifer Krauter[1], Nicolas Zuber[1], Frederic Hummel[2], Florian Meinert[1], Robert Löw[1], Peter Schmelcher[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We report on the onset dynamics of a collision between an ion and a Rydberg atom in a highly excited S-state. Due to a large number of avoided crossings in the pair state potential, the dynamics can be quite complex but also provides a lot of possibility to manipulate and control the collision rates by changing the adiabaticity of the system. In our setup we can create Rb^+ ions and highly excited Rydberg sates independently. Owed to a very precise control of electric stray fields, we can conduct our measurements without the need of an additional ion trap, preventing micromotion in our experiments. By using a high-resolution ion microscope, we can directly observe the ions and Rydberg atoms in a cold thermal cloud in real space with a resolution of 200 nm. This allows us not only to directly map out the C4 pair interaction potential but also to directly observe the onset of the collisional dynamics. Finally, the experimental results are compared to a multi-channel model based on a Landau-Zener approach, which agrees very well with the experimental results.

Q 1.6 Mon 12:30 HS 1010

Systematic analysis of relative phase extraction in 1D Bose gases interferometry — •Taufiq Murtadho[1], Marek Gluza[1], Nelly Ng[1], Arifa Khatee Zatul[1,2], Sebastian Erne[3], and Jörg Schmiedmayer[3] — [1]Nanyang Technological University, Singapore — [2]University of Wisconsin-Madison, Madison, USA — [3]Technische Universität Wien, Vienna, Austria

Matter-wave interference upon free expansion enables spatially resolved relative phase measurements of two adjacent 1D Bose gases. However, longitudinal dynamics is typically ignored in the analysis of experimental data. We provide an analytical formula showing a correction to the readout of the relative phase due to longitudinal expansion and mixing with the symmetric phase. Furthermore, we assess the error propagation to the estimation of temperature and correlation of the gases with numerical simulation. Our analysis also incorporates experimental systematic errors such as diffraction, recoil, and shot noise from the imaging devices. This work characterizes the reliability and robustness of interferometric measurements, directing us to the improvement of existing phase extraction methods necessary to observe new physical phenomena in cold-atomic quantum simulators.

Q 1.7 Mon 12:45 HS 1010

Quantum phases of hardcore bosons with repulsive dipolar density-density interactions on two-dimensional lattices — •Jan Alexander Koziol[1], Giovanna Morigi[2], and Kai Phillip Schmidt[1] — [1]Department of Physics, Staudtstraße 7, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany — [2]Theoretical Physics, Saarland University, Campus E2.6, D-66123 Saarbrücken, Germany

We analyse the ground-state quantum phase diagram of hardcore Bosons interacting with repulsive dipolar potentials. The bosons dynamics is described by the extended-Bose-Hubbard Hamiltonian on a two-dimensional lattice The ground state results from the interplay between the lattice geometry and the long-range interactions, which we account for by means of a classical spin mean-field approach. This extended classical spin mean-field theory accounts for the long-range density-density interaction without truncation. The mean-field analysis is limited by the size of the considered unit cells. We consider three different lattice geometries: square, honeycomb, and triangular. In the limit of zero hopping the ground state is always a devil's staircase of solid (gapped) phases. Such crystalline phases with broken translational symmetry are robust with respect to finite hopping amplitudes. At intermediate hopping amplitudes, these gapped phases melt, giving rise to various lattice supersolid phases, which can have exotic features with multiple sublattice densities. Our results are of immediate relevance for experimental realisations of self-organised crystalline ordering patterns, e.g., with ultracold dipolar atoms in an optical lattice.

Q 2: QED

Time: Monday 11:00–13:00 Location: HS 1015

Q 2.1 Mon 11:00 HS 1015

Quantum optics without quantum paradoxes — •Falk Rühl — Auf der Alm 14, 52159 Roetgen, Germany

A transition from the directed one./.one interaction model, mediated by quanta, to a symmetrical any./.any interaction model, mediated by EM-waves propagating in $\mathbb{R}^3$, allows a paradox-free explanation of all effects observed in quantum optical experiments.

In a detection model based on an any./.any interpretation, the total energies of weakly bound electrons in a detector are driven to a continuous random walk, by the local superposition of the EM-fields of all sources of radiation. In the rare instance, where a random walk approaches the binding energy, even extremely weak superadded pulses of EM-radiation, e.g. received from distant sources under investigation, can trigger an event-like release of an electron, that carries the binding energy. Suitably scaled, the count rate $r(a)$, as a function of the power $a \geq 0$, absorbed from the source illumination, has the asymptotic linear branches $r(a) \geq \max\{0, a+d-1\}$, that are connected by a smooth transition in the "tunnel regime" around $d+a=1$. The absorption of amplitude-/phase-modulated radiation is resonantly enhanced only, if the radiation drives closed cycles in the rotating frames of the detecting oscillators, which makes only a small subset of the continuously evolving and radiating "beable" states of sources also "observable".

The "late quantization", the result of a resonant radiation./.target interaction, eliminates "quantum jumps", and all quantum transport paradoxes, that have their roots in the futile attempt to base the interpretation on an "early quantization" of the sources.

Q 2.2 Mon 11:15 HS 1015

Correlations of the Quantum Vacuum in a Nontrivial Analogue Spacetime — •Cristofero Oglialoro[1], Frieder Lindel[2], Fabian Spallek[1], and Stefan Yoshi Buhmann[1] — [1]University of Kassel, Germany — [2]University of Freiburg, Germany

A fascinating aspect of quantum mechanics is that it predicts non-vanishing fluctuations in the electromagnetic ground state. Despite many macroscopic effects being attributed to this fluctuating vacuum field, it has only recently become possible to measure these fluctuations directly via electro-optic sampling. This allowed to access the two-point correlation function of the vacuum field at distinct spacetime regions and to study its spacetime structure [1]. The formalism of macroscopic quantum electrodynamics serves to describe field propagation within nonlinear dispersive media theoretically and predicts the traces of the quantum vacuum in the electro-optic sampling signal and its spacetime structure [2]. In this framework, we discuss how additional external fields alter the spacetime structure of the sampled vacuum fluctuations by interpreting the effects of the external field as a nontrivial analogue spacetime.

[1] F. F. Settembrini, et al., Nat. Commun. 13, 3383 (2022).
[2] F. Lindel, et al., Phys. Rev. A 102, 041701(R) (2020).

Q 2.3 Mon 11:30 HS 1015

Quantum radiation in a dielectric with time-dependent dissipation — •Sascha Lang[1,2,3], Stefan Yoshi Buhmann[1], Ralf Schützhold[2,4,3], and William G. Unruh[5] — [1]University of Kassel, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Universität Duisburg-Essen, Germany — [4]Technische Universität Dresden, Germany — [5]University of British Columbia, Canada

Rapidly changing system parameters in tuneable dielectrics can trigger the spontaneous conversion of quantum vacuum fluctuations into real photons [1]. A famous example is the production of photon pairs in the presence of strongly non-adiabatic refractive index modulations $n(t)$. Unlike in relativistic quantum field theory, the evolution of quantum vacuum fluctuations in dielectrics is affected by dispersion and dissipation. A consistent description of the quantum dynamics in explicitly time dependent environments requires a microscopic model that can be quantised canonically.

We present an approach which models the medium via a continuous set of harmonic oscillators [2] and accounts for dissipation by coupling those medium oscillators to a scalar environment field [3]. As an example of quantum radiation, we consider particle pair creation in a medium with a non-adiabatically varying dissipation strength.

[1] F. Belgiorno, S. L. Cacciatori & F. Dalla Piazza: Eur. Phys. J. D **68**, 134 (2014)
[2] Hopfield, Phys. Rev. **112**, 1555 (1958)
[3] Lang, Schützhold & Unruh: Phys. Rev. D 102, 125020 (2020)

Q 2.4 Mon 11:45 HS 1015

Numerical evaluation of Casimir-Lifshitz forces in the time domain — •Carles Martí Farràs[1], Philip Kristensen[2,3], Bettina Beverungen[1], Francesco Intravaia[1], and Kurt Busch[1,4] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]DTU Electro, Technical University of Denmark, Lyngby, Denmark — [3]NanoPhoton - Center for Nanophotonics, Technical University of Denmark, Lyngby, Denmark — [4]Max Born Institute, Berlin, Germany

Fluctuation-induced phenomena, stemming from both quantum and thermal fluctuations, which are inherent in nature, exhibit fascinating effects that become particularly relevant at short-length scales. A notable example is the Casimir effect, which describes a usually attractive force between electrically neutral macroscopic objects. Apart from their fundamental interest, a comprehensive understanding of such interactions is crucial for the progress of nanostructured device development. Since analytical calculations are only possible for a few highly symmetric geometries, this has prompted the development of methods to numerically evaluate Casimir forces in the context of complex geometries and material models. Here, we present a time-domain finite-element-based numerical approach leveraging the capabilities of the discontinuous Galerkin time-domain (DGTD) method. It allows to accurately assess the electromagnetic response of the system, providing a robust and efficient framework for systematically evaluating Casimir forces in a wide range of configurations.

Q 2.5 Mon 12:00 HS 1015

Redfield-pseudomodes theory — •Felix Riesterer, Lucas Weitzel Dutra Souto, Andreas Buchleitner, and Dominik Lentrodt — University of Freiburg, Freiburg, Germany

Quantum systems which are strongly coupled to a large environment or a bath are difficult to tackle theoretically, since common approximations such as weak-coupling Master equations break down in this regime. A commonly used concept to circumvent this difficulty is to include the bath degrees of freedom responsible for the strong coupling into the system. This idea underlies a whole family of approaches known as pseudomodes theory, whose most well-known representative is the open Jaynes-Cummings model in cavity quantum electrodynamics. In general, pseudomodes are an approach to describe the dynamics of open quantum systems where instead of tracing out the complete environment, discrete auxiliary modes featuring Lindbladian loss are retained in the system. We present a generalized pseudomodes concept which allows for a more general Markovian loss described by a Redfield equation. We then apply the generalized Redfield-pseudomodes approach within the framework of cavity quantum electrodynamics. In particular, we derive a pseudomodes expansion of the spectral density, which has to be matched with the original continuum theory to guarantee the equivalence of the Redfield-pseudomodes representation. We then compare the fitting capability of the generalized mode expansion of the spectral density to that of the corresponding expansion of the in the Lindblad-pseudomodes representation for different exemplary cavity geometries, demonstrating a significantly improved convergence.

Q 2.6 Mon 12:15 HS 1015

Heat transport using nonreciprocal media — •Nico Strauss, Omar Jesús Franca Santiago, and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, 34132 Kassel, Germany

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

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

Q 2.7 Mon 12:30 HS 1015

Quantum free-electron laser: single- and multiphoton transitions — •Peter Kling[1] and Enno Giese[2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Quantentechnologien, Wilhelm-Runge-Straße 10, 89081 Ulm, Deutschland — [2]Technische Universität Darmstadt, Fachbereich Physik, Institut für Angewandte Physik, Schlossgartenstr. 7, 64289 Darmstadt, Deutschland

The quantum free-electron laser ("Quantum FEL") is a proposed x-ray source. In contrast to existing devices ("classical FEL"), where an electron in the undulator follows continuous trajectories and emits many photons, an electron in the Quantum FEL occupies only two resonant levels on a discrete momentum ladder and emits at most one photon. We investigate the influence of multiphoton corrections [1] on the dynamics of the electron and on the photon statistics of the emitted radiation. Moreover, we (i) try to identify the challenges for an experimental realization [2] and (ii) study the transition between classical and quantum regime in the FEL from a fundamental point of view [3].

[1] P. Kling, E. Giese, Phys. Rev. Research 5, 033057 (2023).
[2] A. Debus et al., Phys. Scr. 94, 074001 (2019).
[3] C. M. Carmesin et al., Phys. Rev. Research 2, 023027 (2020).

Q 2.8 Mon 12:45 HS 1015

Dicke-like superradiance of distant noninteracting atoms — •Manuel Bojer and Joachim von Zanthier — Friedrich-Alexander-Universität Erlangen-Nürnberg, Quantum Optics and Quantum Information, Staudtstr. 1, 91058 Erlangen, Germany

Fully excited two-level atoms separated by less than the transition wavelength cooperatively emit light in a short burst, a phenomenon called superradiance by R. Dicke in 1954 [Phys. Rev. 93, 99 (1954)]. The burst is characterized by a maximum intensity scaling with the square of the number of atoms N and a temporal width reduced by N compared to the single atom spontaneous decay time. Both effects are usually attributed to a synchronization of the electric dipole moments of the atoms occurring during the process of light emission. Contrary to this explanation, it was recently shown by use of a quantum path description that the peak intensity results from the quantum correlations among the atoms when occupying symmetric Dicke states. Here we investigate from this perspective the temporal evolution of the ensemble, starting in the small sample limit, i.e., when the atoms have mutual separations much smaller than the transition wavelength λ and pass down the ladder of symmetric Dicke states. In addition, we explore the temporal evolution for the case of distant noninteracting atoms with mutual separations much larger than λ. We show that in this case a similar superradiant burst of the emitted radiation is observed if the quantum correlations of the atoms are generated by conditional photon measurements retaining the atomic ensemble within or close to the symmetric subspace.

Q 3: Bosonic Quantum Gases I (joint session Q/A)

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

Q 3.1 Mon 11:00 Aula

Universal Dynamics of Rogue Waves in a Quenched Spinor Bose Condensate — •Ido Siovitz, Stefan Lannig, Yannick Deller, Helmut Strobel, Markus K. Oberthaler, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Universität Heidelberg

Universal scaling dynamics of isolated many-body systems far from equilibrium is a phenomenon documented both in theory and experiment, the mechanisms of which are not yet fully understood. We connect the universal dynamics of a spin-1 gas with rogue-wave like events in the mutually coupled magnetic components of the gas, which propagate in an effectively random potential governed by the nonlinear spin-changing interaction. As a result, real-time instantons appear in the Larmor phase of the spin-1 system as vortices in space and time. We investigate the spatial and temporal correlations of these events to find two mutually related scaling exponents defining the coarsening evolution of length and time scales, respectively.

Q 3.2 Mon 11:15 Aula

Nondegenerate two-photon absorption in gaseous xenon for Bose-Einstein condensation of vacuum-ultraviolet photons — •Thilo vom Hövel, Franz Huybrechts, Eric Boltersdorf, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Motivated by work with cold atomic ensembles, Bose-Einstein condensation has in recent years also been realized for two-dimensional gases of visible-spectral-range photons. For this, e.g., a dye solution-filled optical microcavity is utilized to thermalize a photon gas via repeated cycles of absorption and emission by dye molecules. In previous work, we proposed to employ a similar platform for the construction of a coherent light source in the VUV (100 - 200 nm wavelength), a spectral range in which it is difficult to operate lasers.

For Bose-Einstein condensation of VUV photons, a thermalization mediator other than the dye system needs to be identified, as the latter is unsuitable in light of the high photon energies. One candidate is the quasimolecular xenon system, with absorption on the $5p^6 \rightarrow 5p^5 6s$ transition at 147 nm and emission on the Stokes-shifted second excimer continuum around 172 nm wavelength. In pure xenon at currently investigated pressures, however, the pronounced spectral gap between absorption and emission impedes efficient contact between photon gas and thermalization mediator. We here report on spectroscopic results of an experimental scheme devised to enhance the (re-)absorption of photons emitted around 172 nm, based on a nondegenerate two-photon process induced by the provision of an auxiliary photon field.

Q 3.3 Mon 11:30 Aula

Projection Optimization Method for Open-Dissipative Quantum Fluids and its Application to a Single Vortex in a Photon Bose-Einstein Condensate — •Joshua Krauss[1], Marcos Alberto Gonçalves dos Santos Filho[1,2], Francisco Ednilson Alves dos Santos[2], and Axel Pelster[1] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil

Open dissipative systems of quantum fluids have been well studied numerically. In view of a complementary analytical description we extend here the variational optimization method for Bose-Einstein condensates of closed systems to open-dissipative condensates. The resulting projection optimization method is applied to a complex Gross-Pitaevski equation, which models phenomenologically a photon Bose-Einstein condensate. Together with known methods from hydrodynamics we obtain an approximate vortex solution, which depends on the respective open system parameters and has the same properties as obtained numerically in the literature.

[1] J. Krauß, M.A.G. dos Santos Filho, F.E.A. dos Santos, and A. Pelster, arXiv:2311.10027

Q 3.4 Mon 11:45 Aula

Out-of-equilibrium dynamics and phases of an atomic BEC coupled to an optical cavity — •Gage Harmon[1], Giovanna Morigi[1], and Simon Jäger[2] — [1]Saarland University — [2]University of Kaiserslautern-Landau

We study the pattern formation of a laser-driven atomic Bose-Einstein condensate coupled to a single lossy mode of an optical cavity. In our work, we focus on the regime where the effective cavity detuning depends strongly on the dispersive AC Stark shift, and where the cavity relaxation rate is fast compared to the typical atomic relaxation rate. This results in a feedback between the atomic pattern and cavity field that allows for a parameter regime where the cavity field is unable to stabilize the atomic configuration. Instead, the system enters a dynamical phase where the atomic pattern and cavity field exhibit oscillations. We analyze this behavior using a mean-field approach that describes the coupled dynamics of the atoms and cavity field. In addition, working in the bad-cavity regime allows us to derive equations of motion where the cavity degrees of freedom are eliminated, massively improving the integration time. We benchmark and validate these equations of motion and showcase that the existence of limit cycle phases does not require a treatment of the cavity field and atoms to be on equal timescales. Remarkably, we demonstrate that the presence of non-conservative forces which require both, dissipation and a prominent AC Stark shift, are the key mechanisms that results in limit cycle and chaotic phases.

Q 3.5 Mon 12:00 Aula

Bose-Einstein condensation of photons in a vertical-cavity surface-emitting laser — Maciej Pieczarka[1], Marcin Gebski[2], Aleksandra N. Piasecka[1], James A. Lott[3], •Axel Pelster[4], Michał Wasiak[2], and Tomasz Czyszanowski[2] — [1]Department of Experimental Physics, Wrocław University of Science and Technology, Poland — [2]Institute of Physics, Łodź University of Technology, Poland — [3]Institute of Solid State Physics and Center of Nanophotonics, Technical University Berlin, Germany — [4]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany

Here we show the Bose-Einstein condensation of photons in a broad-area vertical-cavity surface-emitting laser with positive cavity mode-gain peak energy detuning. We observed a Bose-Einstein condensate in the fundamental transversal optical mode at the critical phase-space density. The experimental results follow the equation of state for a two-dimensional gas of bosons in thermal equilibrium, although the extracted spectral temperatures were lower than those of the device. This is interpreted as originating from the driven-dissipative nature of the device and the stimulated cooling effect. In contrast, non-equilibrium lasing action is observed in the higher-order modes in a negatively detuned device. Our work opens the way for the potential exploration of superfluid physics of interacting photons mediated by semiconductor optical non-linearities. It also shows great promise for enabling single-mode high-power emission from a large aperture device.

[1] M. Pieczarka, M. Gebski, A.N. Piasecka, J.A. Lott, A. Pelster, M. Wasiak, and T. Czyszanowski, arXiv:2307.00081

Q 3.6 Mon 12:15 Aula

Ramsauer Townsend effect and Bragg scattering in an analogue cosmology experiment — •Marius Sparn[1], Elinor Kath[1], Nikolas Liebster[1], Christian F. Schmidt[2], Álvaro Parra-López[3], Mireia Tolosa-Simeón[4], Helmut Strobel[1], Stefan Floerchinger[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena — [3]Departamento de Física Teórica and IPARCOS, Universidad Complutense de Madrid — [4]Institut für Theoretische Physik III, Ruhr-Universität Bochum

Cosmological particle production arises when a quantum field is subject to an expanding metric. This phenomenon heavily depends on the details of the cosmological history. Strikingly, this relativistic, time-dependent process can be mapped to a scattering problem, described by a non-relativistic stationary Schroedinger-equation, wherein the scattering potential is determined by the specific form of the expansion. Here we present results from an analogue cosmology experiment with a two-dimensional Bose-Einstein condensate, simulating a scalar quantum field in a FLRW-spacetime [1]. We use the scattering framework to investigate instructive examples, such as a box potential, corresponding to a singular expanding space-time as well as a periodic potential, corresponding to a periodic expansion and contraction. The measured spectra of produced particles reveal features analogue to resonant forward (Ramsauer-Townsend) scattering and Bragg scattering, respectively. [1] Viermann, C. et al. Nature 611, 260-264 (2022)

Q 3.7 Mon 12:30 Aula

Dynamics of polaron formation in weakly interacting 1D Bose gases — •Martin Will and Michael Fleischhauer — University of Kaiserslautern-Landau

We discuss the dynamics of the formation of a Bose polaron when an impurity is injected into a weakly interacting one-dimensional Bose condensate. While for small impurity-boson couplings, this process can be described within the Froehlich model as emission, and binding of Bogoliubov phonons, this is no longer adequate if the coupling becomes strong. To treat this regime, we consider a mean-field approach beyond the Froehlich model which accounts for the backaction to the condensate, complemented with Truncated Wigner simulations to include quantum fluctuation. For the stationary polaron we find a periodic energy-momentum relation and non-monotonous relation between impurity velocity and polaron momentum including regions of negative impurity velocity. Consequently, the impurity undergoes Bloch oscillations when subject to a constant force. Studying the polaron formation after turning on the impurity-boson coupling (i) quasi-adiabatically and (ii) in a sudden quench, we find a rich scenario of dynamical regimes. Due to the build-up of an effective mass, the impurity is slowed down even if its initial velocity is below the Landau critical value. For larger initial velocities we find deceleration and even backscattering caused by emission of density waves or grey solitons and subsequent formation of stationary polaron states.

Q 3.8 Mon 12:45 Aula

Solitons on the surface of a sphere — •Alexander Wolf[1,2], Vladimir Konotop[3], and Maxim Efremov[2] — [1]Institute of Quantum Physics and Center for Integrated Quantum Science and Technology (IQ^{ST}), Ulm University, D-89081 Ulm, Germany — [2]German Aerospace Center (DLR), Institute of Quantum Technologies, D-89081 Ulm, Germany — [3]Departamento de Física and Centro de Física Teórica e Computacional, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, Ed. C8, Lisboa 1749-016, Portugal

The recent realization of ultracold quantum gases in a shell geometry [1] paves the way towards a Bose-Einstein condensate (BEC) that is trapped tightly onto the surface of a sphere. We investigate the existence and stability of solitons that appear in this system using the two-dimensional (2D) Gross-Pitaevskii equations (GPE). Comparing our results to the 2D plane, we find that the scale invariance of the GPE is broken due to the curvature and compactness of the shell geometry. Consequently, the familiar Townes solitons [2] appear only when the BEC is strongly localized in a small region of the sphere surface.

[1] R. A. Carollo *et al.*, Nature (London) **606**, 281 (2022).
[2] B. Bakkali-Hassani *et al.*, Phys. Rev. Lett. **127**, 023603 (2021).

Q 4: Hybrid Quantum Systems

Time: Monday 11:00–13:00 Location: HS 1199

Q 4.1 Mon 11:00 HS 1199

Cavity optomechanics with polymer-based multi-membrane structures — •Lukas Tenbrake[1], Sebastian Hofferberth[1], Stefan Linden[2], and Hannes Pfeifer[3] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Physics, University of Bonn, Germany — [3]Department of Microtechnology and Nanoscience, Chalmers University of Technology, Gothenburg, Sweden

Despite their application in multiple fields, ranging from quantum sensing to fundamental tests of quantum mechanics, conventional state-of-the-art cavity optomechanical experiments have been limited in their scaling towards systems with multiple resonators. 3D direct laser writing offers a new approach of fabricating multi-membrane structures that can be directly integrated into fiber Fabry-Perot cavities. Here, we experimentally demonstrate direct laser-written stacks of two or more coupled membranes – with normal-mode splittings of up to a MHz – interfaced by fiber cavities. We present finite element simulations for the optimization of the mechanical coupling and investigate the collective optomechanical coupling of multi-membrane stacks (with single-membrane vacuum optomechanial coupling strengths of $\gtrsim 30\,\mathrm{kHz}$). We present our first experimental results and give an outlook on the scalability of the system to an even larger number of coupled mechanical oscillators. Aside from tests of fundamental properties of multimode optomechanical systems, applications for sensing or routing of vibration in acoustic metamaterials and circuits are envisaged.

Q 4.2 Mon 11:15 HS 1199

Theory of phase-adaptive parametric cooling — •Pardeep Kumar[1], Alekhya Ghosh[1,2], Christian Sommer[3], Fidel G. Jimenez[4], Vivishek Sudhir[5,6], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, D-91058 Erlangen, Germany — [3]AQT, Technikerstraße 17, 6020, Austria — [4]Pontificia Universidad Católica del Perú, Av. Universitaria 1801, San Miguel 15088, Peru — [5]LIGO Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA — [6]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

An adaptive phase technique has been proposed for the parametric cooling of the mechanical oscillators. The method calls for a sequence of periodic adjustments of the phase of a parametric modulation of the mechanical oscillator that is conditioned on measurements of its two quadratures. This technique indicates a pure exponential loss of the thermal energy at initial high occupancies. As the quantum ground state is approached, the phase adaptive scheme leads to residual occupancies at the level of a few phonons owing to the competition between parametric amplification of the quantum fluctuations and the feedback action. In contrast to available parametric feedback cooling techniques, the proposed phase-adaptive technique remains immune from the extraneous heating arising from direct modulation of the radiation pressure force.

Q 4.3 Mon 11:30 HS 1199

Interfacing Rydberg atoms with an electromechanical oscillator at 4K — •Cedric Wind, Johanna Popp, Leon Sadowski, Julia Gamper, Valerie Mauth, Wolfgang Alt, Hannes Busche, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

We currently construct a novel setup to interface optically controlled Rydberg atoms with an on-chip electromechanical oscillator at 4K. This talk discusses the prospects of implementing this hybrid quantum system and presents our progress on the construction of the cryogenic setup. As a first experiment, we will explore the cooling of a GHz mechanical mode to its quantum mechanical ground state by extracting phonons via a dissipative extraction of microwave photons via Rydberg atoms.

Our system combines a closed-cycle cryostat with vibration isolation with a classical room-temperature setup from which ultra-cold atoms are magnetically transported into the cryo-region. Besides providing the suppression of thermal noise required to study electromechanical oscillators near their ground state, the enhanced vacuum condition due to cryo-pumping eliminates the need to bake the vacuum system and enables fast exchange and cooling of samples in the experiment region. We will discuss how the setup, the on-chip superconducting magnetic trap and the electromechanical oscillator design have been optimized for the planned experiment.

Q 4.4 Mon 11:45 HS 1199

Waveguide QED with Rydberg superatoms — •Lukas Ahlheit, Daniil Svirskiy, Jan de Haan, Christoph Biesek, Nina Stiesdal, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

The field of Waveguide QED investigates how light in a single mode propagates through a system of localized quantum emitters. If the coupling between individual photons and emitters is sufficiently strong, the photons mediate an effective interaction between the emitters, creating a many-body system.

We use Rydberg superatoms as quantum emitters. These are ensembles of $N \sim 10\,000$ atoms confined to within the Rydberg blockade volume, such that each ensemble only supports a single excitation. Every collective emitter has highly directional emission, and couples strongly to even few-photon fields. The directed emission into the mode of the driving field realizes a waveguide-like system in free-space without any actual light-guiding elements.

This talk will discuss how we scale our system from one to few strongly coupled superatoms with low dephasing. We use a magic wavelength optical lattice to trap atoms in both the ground- and the Rydberg state. This reduces atomic motion and limits dephasing of the collective excitation. With extended coherence times, we will be able to show how the propagation of quantized light fields through a small emitter chain results in photon-photon correlations and entanglement between the emitters.

Q 4.5 Mon 12:00 HS 1199

Quantum repeater node with free-space coupled photons from trapped $^{40}Ca^{+}$ ions — •Max Bergerhoff, Omar Elshehy, Stephan Kucera, Matthias Kreis, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The quantum repeater cell according to [1] is a fundamental building block for the realisation of large distance quantum networks. By dividing a transmission link in asynchronously driven segments it is possible to overcome the loss scaling of direct transmission. The advantage of this protocol has already been demonstrated with single atoms [2] in a cavity and single ions in a large cavity [3]. We report on the implementation of a quantum repeater cell with free-space coupled photons from two $^{40}Ca^{+}$ ions in the same Paul trap as memories. Atom-photon entanglement is generated asynchronously [4] by controlled emission of single photons from the individually addressed ions, and separate single-mode fiber coupling. Photon-photon entanglement is then generated by a Mølmer-Sørensen gate [5] on the ions. We discuss the probability and rate scaling due to the asynchronous sequence, as well as the fidelity of the final photon-photon state. In this context the perspective of a new ion trap setup with integrated sub-mm cavity is discussed and its implementation status is presented.

[1] D. Luong et al., Appl. Phys. B 122, 96 (2016)
[2] S. Langenfeld et al., Phys. Rev. Lett. 126, 30506 (2021)
[3] V. Krutyanskiy et al., Phys. Rev. Lett. 130, 213601 (2023)
[4] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[5] K. Mølmer and A. Sørensen, Phys. Rev. Lett 82, 1835-8 (1999)

Q 4.6 Mon 12:15 HS 1199

optical microcavity with coupled single SiV and GeV centers in a nanodiamond for a quantum repeater platform — •Selene Sachero[1], Robert Berghaus[1], Gregor Bayer[1], Florian Feuchmayr[1], Andrea B Filipovski[1], Patrick Maier[1], Lukas Antoniuk[1], Niklas Lettner[1], Marco Klotz[1], Richard Waltrich[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Tours University, France

Quantum repeater are essential building block to create a large scale quantum communication network. An ideal quantum repeater nodes efficiently link a quantum memory with photons serving as flying qubits. By coupling group defect centers to an open Fabry-Perot cavity, such an interface can be created.

As such a platform, we propose a fully tunable cavity, composed by two Bragg mirrors, which allows short cavity lengths, and provides efficient coupling of quantum emitters at 4 K.

Here, we show the good optical properties of a single germanium vacancy (GeV-) and its transfer to a Fabry-Perot cavity. The coupling of the GeV- into the resonator is achieved maintaining a high finesse.

Moreover, we couple an individual SiV- into our resonator. We perform resonant photoluminescence measurements, and observe a spectrally stable emitter with a linewidth close to the Fourier limit. We demonstrate coherent optical driving and all-optical initialization and readout of the electron spin in a high external magnetic field.

Q 4.7 Mon 12:30 HS 1199

Hybrid Quantum Photonics With One Dimensional Photonic Crystal Cavities and Silicon Vacancy Centers In Nanodiamonds — •Lukas Antoniuk[1], Niklas Lettner[1,2], Anna P. Ovvyan[3,5], Daniel Wendland[3], Viatcheslav N. Agafonov[4], Wolfram H.P. Pernice[3,5], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Universite F. Rabelais, 37200

Tours, France — [5]Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Efficient connection of stationary- and flying qubits posts a formidable challenge, yet is one of the demands for the development of applications like quantum networks, distributed quantum computing and quantum communication. Cavity quantum electrodynamics provides enhanced light-matter interaction, hence serving as an attractive tool for spin-photon interfaces. Here, we present our progress of a hybrid quantum photonic interface which interconnects chip-integrated one-dimensional photonic crystal cavities in silicon nitride with negatively charged silicon vacancy centers (SiV) in nanodiamonds. We elaborate on the unique possibilities of dipole alignment by nanomanipulation [1] and show our results on Purcell broadened optical access to the SiV centers electron spin [2].

[1]Lettner et al., arXiv:2310.17198
[2]Antoniuk et al., arXiv:2308.15544

Q 4.8 Mon 12:45 HS 1199

Towards coherent single praseodymium ion quantum memories in optical fiber microcavities — •Sören Bieling[1], Nicholas Jobbitt[1], Roman Kolesov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Universität Stuttgart, 70569 Stuttgart, Germany

Rare earth ions doped into solids show exceptional quantum coherence in their ground-state hyperfine levels. These spin states can be efficiently addressed and controlled via optical transitions and are thus ideally suited to serve as quantum memories and nodes of quantum networks. However, while long storage times, high storage efficiencies and storage on the single photon level have all been demonstrated separately, they could not yet be achieved simultaneously.

We aim to demonstrate both long and efficient single quantum storage in the ground-state hyperfine levels of single Pr^{3+} ions doped into yttrium orthosilicate (YSO) by integrating them as membrane into optical high-finesse fiber-based Fabry-Pérot microcavities. This allows for efficient addressing and detection of individual ions. We report on the design, commissioning and characterization of a next-gen cryogenic scanning microcavity with an integrated, few-μm thick Pr:YSO membrane. First cryogenic, cavity enhanced photoluminescence excitation measurements of a doped Pr:YSO membrane will be reported. Together with the Purcell enhanced emission and ultrapure Pr:YSO membranes this strives to realize efficient and coherent spin-photon interfaces suitable for deployment in scalable quantum networks.

Q 5: Magnetometry

Time: Monday 11:00–13:00 Location: HS 1221

Invited Talk Q 5.1 Mon 11:00 HS 1221

Tailoring design of quantum sensor to biomedical applications — •Victor Lebedev, Simon Nordenstroem, Stefan Hartwig, and Thomas Middelmann — PTB 8.2, Abbestr. 2-12, D-10587 Berlin, Germany

Atomic magnetometers are among the most established types of quantum sensors and can be flexibly engineered to match the signal properties specific to the given application. Biomagnetic studies call for extraordinarily broad parameter ranges – bandwidth, sensitivity and isotropy, to name a few – to be secured in view of burst-like, arbitrarily oriented biological magnetic fields [1]. This implies distinct design decisions for the sensor in the sense of geometry, atomic medium and operation mode, accounting also for the constraints of the clinical laboratory environment and practicality. Here we illustrate the approach by several application cases, and, in particular, with atomic magnetometers for magnetomyography [2], which is characterized by field patterns being beyond the reach of the conventional sensors used in industry and studied in labs. We discuss broader applications of the implemented magnetometer design and further improvements of the measurement technique.

[1] Lebedev et al, in Flexible high performance magnetic field sensors, Springer, 2023.
[2] Marquetand et al, Int. J. Bioelectromagn. 23, 2, 11 (2021).

Q 5.2 Mon 11:30 HS 1221

A Compact Optically Pumped Magnetometer for Biomagnetism in Space — •Sascha Neinert[1,2], Kirti Vardhan[2], Jenichi Felizco[1], Marc Christ[1,2], Kai Gehrke[1], Andreas Thies[1], Olaf Krüger[1], Martin Jutisz[1,2], Mustafa Gündoğan[1,2], Victor Lebedev[3], Stefan Hartwig[3], Simon Nordenström[3], Thomas Middelmann[3], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut gGmbH, Berlin — [2]Humboldt-Universität zu Berlin — [3]Physikalisch-Technische Bundesanstalt, Berlin

Effectively monitoring and diagnosing astronauts' neuromuscular conditions during space missions is crucial for adapting their training. The MyoQuant project is dedicated to investigating the utility of magnetomyography with optically pumped magnetometers (OPMs) to surpass conventional methods in a non-invasive manner.

Leveraging warm alkali atom vapors, laser light, and external magnetic fields, OPMs offer a flexible and non-invasive solution. Our primary objective is to develop a compact Mx-type magnetometer utilizing cesium vapor, delivering high bandwidth and robustness suitable for moderately shielded environments in space.

We provide an overview of the current state of development for our compact OPM and discuss our progress in tailoring the sensor for biomedical applications. Facilitating additive manufacturing of ceramics and investigating wafer-based MEMS vapor cell fabrication techniques, we aim to develop a micro-integrated sensor package for extended space-borne missions.

Q 5.3 Mon 11:45 HS 1221

Integrated magnetic field camera based on diamond NV center infrared absorption ODMR — •Julian M. Bopp[1,2], Hauke Conradi[3], Felipe Perona[2], Anil Palaci[1], Jonas Wollenberg[1], Thomas Flisgen[2], Armin Liero[2], Heike Christopher[2], Norbert Keil[3], Wolfgang Knolle[4], Andrea Knigge[2], Wolfgang Heinrich[2], Moritz Kleinert[3], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany — [3]Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, 10587 Berlin, Germany — [4]Leibniz-Institut für Oberflächenmodifizierung e.V., 04318 Leipzig, Germany

Magnetic field sensors based on diamond nitrogen vacancy (NV) centers reveal outstanding sensitivities at room temperature. Such sensors are attractive for biological applications. Nowadays, multiple sensor types can be distinguished. While fiber-packaged sensors are small, hand-held devices, they cannot record magnetic field images. However, scanning magnetometers and camera-based approaches require bulky optics or moving parts, which render photonic packaging impossible.

In our work, we combine the advantages of fiber-packaged and imaging magnetometers. We propose and demonstrate a chip-integrated, fiber-packaged multi-pixel magnetic field camera (patents US11719765B2, EP4099041A1). The camera employs perpendicularly intersecting infrared and green laser beams to perform spatially resolved ODMR in a diamond substrate.

Q 5.4 Mon 12:00 HS 1221

Compact Fiberized NV based 3D Magnetic Field Sensor — •Jonas Homrighausen[1], Frederik Hoffmann[2], Jens Pogorzelski[2], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, University of Applied Sciences, Münster — [2]Department of Electrical Engineering and Computer Science, University of Applied Sciences, Münster

In the field of quantum magnetometry, ensembles of NV centers in diamond offer high sensitivity, high bandwidth and outstanding spatial resolution while operating at room temperature. Furthermore, the orientation of the defect centers along four crystal axes form an inherent coordinate system that can be exploited to perform vector magnetometry in a single device. For recovering three-dimensional magnetic field information, an external known magnetic field is critical, typically provided by a 3D Helmholtz coil. This however leads to a bulky and lab-bound setup and inhibits any miniaturization of the sensor device. Here, we present a novel approach that facilitates the generation of a localized bias field at the fiber tip and consequently omits the use of external field generation like Helmholtz coils and rare earth magnets. Leveraging pre-selected orientations of diamond microcrystals, we demonstrate vector magnetometry with the uniaxial DC magnetic field. We achieve a sensitivity in the $nT/Hz^{1/2}$ range, microscale spatial resolution and a sensor cross section of <$1mm^2$.

Q 5.5 Mon 12:15 HS 1221

Drone-suspended quantum gradiometer for detection of unexploded ordnance and geo-prospecting (QGrad) — •Gunnar Langfahl-Klabes, Denis Uhland, and Ilja Gerhardt — Leibniz University, Inst. of Solid-State Physics, Appelstr. 2, 30167 Hannover

The QGrad project aims to develop quantum sensors for unshielded airborne magnetometry. We use alkali vapour atoms and gradiometry to subtract signals from multiple magnetometers. This approach holds significance for uncovering hidden raw materials, pipelines, contaminated sites, foundations, and munitions, particularly addressing the challenge of locating land mines and explosive ordnance from past wars for safe clearance.

Our collaboration includes academic partner Leibniz Institute of Photonic Technologies Jena, and industrial partners Asdro GmbH, Optikron GmbH, Supracon AG, and Toptica Photonics AG exploring the gradiometer scheme, developing the required readout components, data processing capabilities and integration for flight use.

In Europe, such quantum magnetometers are commercially unavailable, making QGrad a pioneering initiative. We report on the current status of the project and the gradiometer scheme in particular.

Q 5.6 Mon 12:30 HS 1221

NV-Magnetometry in a two-media laser cavity — •Yves Rottstaedt[1], Lukas Lindner[1], Felix A. Hahl[1], Florian Schall[1], Tingpeng Luo[1], Roman Bek[2], Jan Jeske[1], and Marcel Rattunde[1] — [1]Fraunhofer Institute for Applied Solid State Physics, Freiburg im Breisgau, Germany — [2]Twenty-One Semiconductors GmbH, Stuttgart, Germany

Laser Threshold Magnetometry (LTM) is a novel approach to measure magnetic fields with nitrogen-vacancy (NV) centres in diamonds which can enable a significant improvement in sensitivity while taking advantage of the NV magnetometry characteristics of room-temperature vector magnetometry and the ability to measure on background fields. Instead of simply collecting the photoluminescence emitted by pumping the NV centres, the idea of LTM is to build a cavity with diamond as the laser medium using the non-linear optical cavity to effectively amplify changes in the optical signal. So far it has only been achieved in an externally seeded amplification cavity due to strong absorption in the diamond.

We present an approach of building a cavity also including a second laser medium, in this case an optically pumped semiconductor disc laser. The additional gain provided by the disc laser yields an independent laser cavity for LTM with laser threshold behaviour without the need to seed the cavity externally.

Q 5.7 Mon 12:45 HS 1221

Physics-informed neural networks for analyzing NV-diamond wide-field images of magnetic field distributions measured with a lock-in camera — •Mykhailo Flaks[1,2], Joseph S. Rebeirro[1], Muhib Omar[1], David A. Broadway[2], Patrick Maletinsky[2], Dmitry Budker[1,3,4], and Arne Wickenbrock[3] — [1]Helmholtz Institut Mainz, 55099 Mainz, Germany — [2]Department of Physics, University of Basel, Basel, CH-4056, Switzerland — [3]JGU Mainz, 55128 Mainz, Germany — [4]Department of Physics, University of California, Berkeley, California 94720-7300, USA

We use a novel approach with physics-informed neural networks (PINNs) for analyzing magnetic field distributions. We focus on wide-field images acquired from nitrogen-vacancy center-ensembles in diamond using a lock-in camera. Our method allows to reconstruct source distributions such as currents or magnetization. The inverse reconstruction technique can be used for mapping current distributions in conductors, studying superconductor vortices, and exploring magnetization textures.

We apply these techniques to the images acquired with a microwave-free NV-based imaging device, that uses the ground state level anti-crossing (GSLAC) feature. With the addition of lock-in acquisition of the magnetic field image and the PINN to the inverse problem analysis, we alleviate the effect of the ill-posed nature of the inverse problem and the presence of noise in data. We address the improved sensitivity of the underlying source distribution to advance the measurement method towards a biocompatible sensor for neurons.

Q 6: Solid State Quantum Optics I

Time: Monday 11:00–13:00 Location: HS 3118

Q 6.1 Mon 11:00 HS 3118

Spin properties of erbium dopants in nanophotonic silicon waveguides — •Kilian Sandholzer, Stephan Rinner, Kilian Baumann, Adrian Holzäpfel, Andreas Gritsch, and Andreas Reiserer — Technical University of Munich, Munich Center for Quantum Science and Technology, and Max Planck Institute for Quantum Optics, Garching, Germany

The optical transitions of 4f-electrons in implanted erbium ions are in the telecommunication range making this solid-state system well suited for quantum networks. The incorporation in silicon allows us to use industrial nanofabrication to shape the optical properties of the erbium ions via photonic mode engineering. Our implantation and annealing recipe provide reproducible site integration with promising spin properties of the erbium 4f-electrons. The crystal field splits the lowest spin-degenerate electronic state by 2.6 THz and 2.4 THz in the ground and excited state manifold, respectively, creating two optically coupled isolated effective spin-1/2 systems. We measure the strength and orientation of the effective g-tensors by spectroscopy of a rotating sample in an external magnetic field. Furthermore, the lifetime of the ground-state electron spin is measured using spectral hole burning in dependence of temperature and magnetic field. We find a lower bound of 1 s for the spin lifetime at temperatures below 4.5 K and observe an Orbach-type suppression at higher temperatures. These spin properties are measured on commercially fabricated samples[1] promising easy scalability of this quantum spin-photon interface.

[1] S. Rinner et al., *Nanophotonics* **12**, 3455, (2023)

Q 6.2 Mon 11:15 HS 3118

Design of a high-speed graphene optical modulator on Si3N4 platform for on-chip communication — •Ashraful Islam Raju[1], Pawan Kumar Dubey[1], Rasuole Lukose[1], Christian Wenger[1,2], Andreas Mai[1,3], and Mindaugas Lukosius[1] — [1]IHP-Leibniz Institut für innovative Mikroelektronik, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]BTU Cottbus Senftenberg, Platz der Deutschen Einheit 1, 03046 Cottbus, Germany — [3]Technical University of Applied Science, Hochschulring 1, 15745 Wildau, Germany

Electro-absorption (EA) optical modulator is essential for the advancement of on-chip optical signal processing. While silicon-photonics is a prime candidate, graphene photonics has garnered significant attention due to its remarkable electrical and optical properties. Graphene modulators typically use silicon-on-insulator (SOI) platforms, but Siliconnitride on-silicon-dioxide (Si3N4-on-SiO2) is emerging as a promising alternative with low optical losses and wide compatibility. Despite potential advantages, achieving both high-speed and large modulation efficiencies simultaneously in a single graphene-based device has been challenging. To address this, we designed and simulated a waveguide-coupled double-layer graphene EA modulator on the Si3N4-on-SiO2 platform. We conducted detailed simulations to optimize waveguide dimensions, optical modes, and graphene layer spacing for optimum device performance. Simulation shows a 140 GHz bandwidth, 35 dB extinction ratio (equivalent to a 0.16 dB/um modulation depth), and a low 1.1 dB insertion loss at a wavelength of λ=1550 nm.

Q 6.3 Mon 11:30 HS 3118

An ultra-broadband, integrated mid-infrared photon pair source — •Abira Gnanavel, Franz Roeder, René Pollmann, Olga Brecht, Christof Eigner, Laura Padberg, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Broadband photon-pairs from parametric down-conversion (PDC) are of interest for spectroscopy at low light levels and applications such as quantum optical coherence tomography or entangled two-photon absorption.

Here, we present a type II PDC source realised in a 40 mm long in-house fabricated, dispersion engineered periodically poled Ti:$LiNbO_3$ waveguide yielding ultra-broadband, non-degenerate photon pairs with photons in the near-infrared and mid-infrared regime. A broad spectrum is achieved by matching both group velocities and group velocity dispersion of the signal and idler photons centered at 850 nm and 2800 nm, respectively. The spectral bandwidth of the photons exceeds 23 THz when pumping with a low-cost cw laser diode. A higher bandwidth in the frequency domain results in tighter correlations in the time domain and thus an increased photon simultaneity. This is especially desirable for ultrafast spectroscopy applications because it enables better measurement precision. We present first measurement results of the generated PDC light which are in high correspondence with the simulations.

Q 6.4 Mon 11:45 HS 3118

Trapping of Nanodiamonds using Optical Tweezers — •Alena Erlenbach, Isabel Cardoso Barbosa, Jonas Gutsche, Stefan Dix, Dennis Lönard, and Artur Widera — Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern-Landau, Erwin-Schroedinger-Str. 46, 67663 Kaiserslautern, Germany

The nitrogen-vacancy-center (NV) in diamond is a promising nanoprobe for measuring temperature and magnetic fields, for which they are incorporated into photonic structures such as waveguides. To optimize the excitation of the NV centers and the detection of their fluorescence through the photonic structure, it is necessary to control the nanodiamonds positions during the fabrication process precisely. Therefore, an optical-tweezer-setup can be incorporated into structuring systems to control the position of the nanodiamonds. In this work, we examine the trapping of nanodiamonds in optical tweezers to quantify the influence of different parameters for trapping, particularly the size of the nanodiamonds. Statistical measurements of nanodiamonds in different solvents reflect that trapping is more efficient for smaller particles. This observation agrees with a simple model considering the contributions of gradient and scattering forces. Furthermore, first nanoparticles were trapped in different solvents, suitable for mixing with photoresists needed to fabricate photonic structures. The results show initial requirements for positioning nanodiamonds in solutions prior to fabricate photonic structures with integrated NV centers.

Q 6.5 Mon 12:00 HS 3118

Pulse shaping approaches for quantum dot coherent control — •Vikas Remesh[1], Florian Kappe[1], Yusuf Karli[1], Ria Kraemer[2], Thomas Bracht[3], Armando Rastelli[4], Doris Reiter[3], Stefan Nolte[2], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Abbe Center of Photonics, Friedrich Schiller University Jena, Germany — [3]Condensed Matter Theory, Department of Physics, TU Dortmund, Germany — [4]Johannes Kepler University Linz, Linz, Austria

Shaped laser pulses have been remarkably effective in investigating and controlling various light-matter interactions spanning a broad area of research. In quantum technologies, the techniques to shape complex spatiotemporal waveforms have found renewed interest, for instance in coherent control of quantum dots [1] and spectrotemporal mode shaping in parametric amplification and so on. In this talk, I will navigate through the impact of pulse shaping techniques in nanospectroscopy and how it enabled efficient preparation schemes in quantum dots, based on our recent works [2]. Afterwards, I will conclude with my vision on the future scope of nanophotonics-assisted-quantum technology roadmap. [1] Photonic Quantum Technologies: Science and Applications 1, 53 (2023) [2] Nano Letters 22, 6567 (2022), Materials for Quantum Technology 3, 025006 (2023), APL Photonics 8, 101301 (2023)

Q 6.6 Mon 12:15 HS 3118

Niobium-based plasmonic superconducting photodetectors for near- and mid-IR up to 12 μm — •Sandra Mennle, Philipp Karl, Monika Ubl, Ksenia Weber, Pavel Ruchka, Philipp Flad, Mario Hentschel, and Harald Giessen — 4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Photon-based applications such as quantum technologies have become an important field of research, which requires fast and reliable detectors. Moreover, applications in the mid-IR like spectroscopy are in need for highly efficient photodetection. Superconducting nanowire photon detectors feature a great potential due to their high efficiency and sensitivity.

To enhance the absorption at larger wavelengths in the IR spectral range, a plasmonic perfect absorber geometry is used, which utilizes an impedance-matched plasmonic resonance in combination with a spacer layer and a reflector.

In this work we present detectors which reach an absorption of over 95% for wavelengths up to 4 μm and demonstrate nanostructures with 90% absorption in the 8-12 μm spectral range. By design, these plasmonic resonances feature a large bandwidth and with simple changes of the geometry the resonance can be easily tuned over a wide spectral range. Another advantage of the plasmonic approach is large angle independence, thus high-NA optics can be used to decrease the spot size, resulting in even smaller detector areas and therefore faster response.

Q 6.7 Mon 12:30 HS 3118

Towards ultra-small superconducting Nb-based plasmonic fiber coupled photodetectors arrays — •Philipp Karl, Sandra Mennle, Monika Ubl, Ksenia Weber, Pavel Ruchka, Mario Hentschel, Philipp Flad, and Harald Giessen — 4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Quantum technologies require high-quality and efficient photodetectors and the ability to detect single photons, which can be provided by superconducting nanowire single photon detectors.

We present a superconducting niobium-based plasmonic perfect absorber detector and with near-100% absorption efficiency in the near-infrared spectral range.

To reach the near-100% absorption over a wide spectral range, we take advantage of resonant plasmonic perfect absorber effects and their high resonant absorption cross-section, to enable ultra-small active areas and short recovery times.

To ensure the perfect coupling, we utilize directly coupled single mode fibers in combination with high NA micro optics, which are printed onto the fibers.

With this knowledge, we demonstrate a scalable pixel detector design, which inherits all the previous excellent detector properties.

Q 6.8 Mon 12:45 HS 3118

Direct measurement of coherent light proportion from a laser source without spectral filtering — •Xi Jie Yeo[1], Eva Ernst[1], Alvin Leow[1], Lijiong Shen[1], Jaesuk Hwang[1], Christian Kurtsiefer[1,2], and Peng Kian Tan[1] — [1]Centre for Quantum Technologies, Singapore, Singapore — [2]National University of Singapore, Singapore, Singapore

We present a method to measure the fraction of coherent light emitted by a practical laser source, using interferometric photon correlations; correlations between photoevents detected at the output ports of an asymmetric Mach-Zehnder interferometer. Using this technique, we characterize the fraction of coherent light emitted by a laser diode transiting across its lasing threshold.

Q 7: Quantum Communication I

Time: Monday 11:00–13:00 Location: HS 3219

Q 7.1 Mon 11:00 HS 3219

Polarization Entanglement Distribution on a Hybrid QKD Link — •Shreya Gouravaram Navalur[1,2], Uday Chandrashekara[2], Gregor Sauer[2,3], and Fabian Steinlechner[2,3] — [1]Friedrich Schiller University, Abbe School of Photonics, Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, Germany — [3]Friedrich Schiller University, Institute of Applied Physics, Abbe Center of Photonics, Jena, Germany

Quantum Key Distribution (QKD) uses quantum properties of light to establish secure encryption keys at a distance. Hybrid QKD links are communication channels that incorporate free-space channels as well as fiberoptic links. Fiber-based channels are efficient, reliable, and QKD can be implemented on existing telecom networks with only minor modifications. Free space links, on the other hand, can provide access in urban areas where fiber infrastructure is not deployed and can also scale to long-distance satellite networks. Thus, hybrid QKD networks, that comprise free-space and fiber segments are one of the promising steps towards achieving the goal of a global quantum internet.

In this work, we build and characterize a polarization-entangled photon source that produces highly non-degenerate pairs of signal and idler photons at suitable wavelengths for free-space and fiber-based transmission. Further, we deploy the source on a small-scale hybrid link in Jena to perform entanglement distribution experiments. This way, we can optimize the photon source and study its behaviour on hybrid links, in a real-world environment outside of ideal lab conditions.

Q 7.2 Mon 11:15 HS 3219

Vacuum mediated photon pair emission by a single atom — •Tobias Frank, Gianvito Chiarella, Pau Farrera, and Gerhard Rempe — Max Planck Institute for Quantum Optics

Single atoms coupled to high finesse optical cavities serve as a key platfrom for future quantum networks, where photonic qubits must be distributed, stored and processed efficiently. This platform offers scalability, either by increasing the number of simultaneously coupled emitters or cavity modes. The development of optical-fiber based high finesse Fabry-Perot resonators facilitates the coupling of spatially independent resonator modes to the same emitter. Our group previously implemented such a system using single ^{87}Rb atoms coupled to two crossed optical fiber cavities in the high cooperativity regime. The versatility of this system enables the implementation of a passively heralded quantum memory [1] and a nondestructive qubit detector [2]. We recently extended the capabilities using three atomic energy levels coupled to the two cavities in a ladder configuration. This configuration generates pairs of single photons which are efficiently coupled into separate optical fibers. Using numerical simulations, we find parameters in the regime of strong coupling, for which our system could generate photon pairs without populating the intermediate atomic state. We explain this process in analogy to STIRAP but mediated by the vacuum field in both cavities.

[1] Brekenfeld, M., Niemietz, D., Christesen, J.D. et al. Nat. Phys. 16, 647-651 (2020) [2] Niemietz, D., Farrera, P., Langenfeld, S. et al. Nat. 591, 570-574 (2021)

Q 7.3 Mon 11:30 HS 3219

New atom-cavity setup for engineering entanglement — •Stephan Roschinski, Johannes Schabbauer, Marvin Holten, and Julian Léonard — Technische Universität Wien, Atominstitut, Stadionallee 2, 1020 Wien, Österreich

The efficient and deterministic generation of entanglement in a many-body system poses a challenge for analog and digital quantum simulators. While atomic platforms provide great scalability, they mostly rely on local couplings, for instance, collisional or Rydberg interactions. We report on the current status of a new experimental apparatus to strongly couple an atomic tweezer array to a fiber-based Fabry-Pérot cavity. The cavity geometry with short length, small mirror diameter, and large curvature, places us in a unique regime with simultaneously high single-atom cooperativity and single-atom addressing and readout. Our setup is optimized for fast repetition rates, owing to loading the tweezer array from a magneto-optical trap which is placed within millimeters from the cavity. In future, harnessing this new control will enable us to engineer entanglement through photon-mediated interactions. Further advantages of this platform include partial non-destructive readout and efficient multi-qubit entanglement operations. In the long term, the proposed platform provides a scalable path to studying many-body systems with programmable connectivity, as well as an efficient atom-photon interface for quantum communication applications.

Q 7.4 Mon 11:45 HS 3219

Discrete-modulated continuous-variable QKD over an atmospheric channel — •Kevin Jaksch[1,2], Thomas Dirmeier[1,2], Jan Schreck[1,2], Yannick Weiser[1,2], Stefan Richter[1,2], Ömer Bayraktar[1,2], Bastian Hacker[1,2], Conrad Rössler[1,2], Imran Khan[1,2], Andrej Krzic[3], Markus Rothe[3], Markus Leipe[3], Nico Döll[3], Christopher Spiess[3], Matthias Goy[3], Florian Kanitschar[4,5], Stefan Petscharning[4], Thomas Grafenauer[4], Bernhard Ömer[4], Christoph Pacher[4], Twesh Upadhyaya[5], Jie Lin[5], Norbert Lütkenhaus[5], Gerd Leuchs[1,2], and Christoph Marquardt[2,1] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, Germany — [4]AIT Austrian Institute of Technology, Center for Digital Safety&Security, Vienna, Austria — [5]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Canada

In future metropolitan QKD networks, atmospheric links can provide secure communication complementary to the fiber backbone. For this, we implemented a discrete-modulated continuous-variable QKD system over an urban 1.7 km atmospheric channel in Jena. After subbinning the transmission to cope with the fluctuating nature of the channel, we study the applicability of a recently published security proof in the finite size regime [1] and a fixed set of implemented error correction codes for secret key generation.

[1] Kanitschar et al., PRX Quantum 4, 040306 (2023)

Q 7.5 Mon 12:00 HS 3219

Boosted quantum teleportation — •Simone Evaldo D'Aurelio[1,2], Matthias Bayerbach[1,2], and Stefanie Barz[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Stuttgart, Germany

Quantum teleportation serves as a fundamental pillar across various quantum applications, spanning from quantum communication to quantum computation. Although photons show great promise in these endeavors, the application of linear optics imposes a limitation, capping the success probability of quantum teleportation at 50%. This limitation arises from the fact that a key component, the Bell-state measurement (BSM), faces constraints in success probability when employing linear optics. Here, we demonstrate an enhanced form of quantum teleportation, so-called boosted teleportation, using linear optics only. Introducing an additional ancilla state in the BSM boosts the success probability of the BSM and thus also of the overall quantum teleportation process. The use of extra photons does introduce a more intricate detection pattern compared to the non-boosted scenario. This complexity reveals more information, leading to a higher success probability. Our results show fidelities between the teleported states and the expected outcomes that surpass the maximum fidelity achievable through classical means. This experiment highlights the potential for advanced quantum teleportation protocols, particularly in the realm of photonic quantum computing.

Q 7.6 Mon 12:15 HS 3219

A phase encoding protocol for satellite Quantum Key Distribution — •Kevin Günthner[1,2], Conrad Rössler[1,2], Bastian Hacker[1,2], Ivan Derkach[3], Vladyslav Usenko[3], and Christoph Marquardt[1,2] — [1]Lehrstuhl für Optische Quantentechnologien, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [3]Department of Optics, Faculty of Science, Palacky University, 17. listopadu 12, 77146 Olomouc, Czech Republic

We report on a novel Quantum Key Distribution (QKD) protocol using relative phase encoding designed and optimized for operational satellite QKD. The protocol is based on the BB84 decoy-state protocol. Its security proof is based on the rigorous finite-size techniques [1] extended by several security aspects of the practical implementation. Besides the quantum state exchange for key creation, the protocol contains two additional time multiplexed parts: a few states at quantum level with deterministic phases and intensities to obtain a live reference error rate and bright reference signals used for Doppler effect compensation, clock recovery and bit synchronization with the satellite (without the need for an absolute time reference) as well as for phase locking of the receiving interferometers [2]. With this approach, the quantum signal train is self-contained and requires no additional reference signals for QKD operation simplifying the practical implementation.

[1] Z. Zhang et al., PRA 95, 012333 (2017)
[2] B. Hacker et al., New J. Physics 25, 113007 (2023)

Q 7.7 Mon 12:30 HS 3219

Temporal mode engineering in pulsed parametric down-

conversion — Laura Serino, •Werner Ridder, Jano Gil-Lopez, Abhinandan Bhattacharjee, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), 33098 Paderborn, Germany

Due to the rise of quantum computing, classical secure communication is put at risk. A safer solution is given by entanglement-based high-dimensional quantum key distribution (HD-QKD). Temporal modes of single photons offer an appealing alphabet for HD-QKD. One fundamental component for this protocol is a photon pair source that generates maximally entangled photon pairs with programmable temporal modes and a finite dimensionality. In this work, we demonstrate such a source. The source is based on a type II parametric down-conversion process in a periodically poled potassium titanyl phosphate waveguide. We pump the source with spectrally shaped light pulses and generate photon pairs in the telecom C band. We base our encoding on so-called cosine-kernel modes (equivalent to time-bins) because they yield maximally entangled states. We can, however, realize other encodings by programming other pump pulse spectra. To characterize the performance of the source, the relation between the second-order broadband correlation function $g^{(2)}$ and the Schmidt number K has been exploited, where $g^{(2)} = 1+1/K$. We demonstrate the generation of photon pairs with dimensionalities from 1 to 9 and explore other coding alphabets.

Q 7.8 Mon 12:45 HS 3219

Clock recovery with single photon clicks for satellite QKD — •Conrad Rössler[1,2], Bastian Hacker[1,2], Kevin Günthner[1,2], and Christoph Marquardt[1,2] — [1]Lehrstuhl für Optische Quantentechnologien, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany

While Quantum Key Distribution (QKD) offers an information theoretical secure way to exchange cryptographic keys, its experimental implementation poses technical challenges, especially in satellite QKD. Since QKD sources work with very weak signals in order to profit from the quantum mechanical no-cloning theorem, the high loss experienced in satellite QKD is particularly disruptive for these fragile states. One way to overcome this is to increase the modulation and sent symbol rate. However, still only very few of these fast modulated signals will arrive at the receiver. For successful key exchange, one must map each of the received states correctly onto the corresponding sent state, which is especially difficult for high rates. Since resources at the satellite are usually limited, the most obvious solution of storing every sent state at the sender for a long time is not practical. Thus, a fast clock recovery is critical in order to allow processing of the received states at runtime. We present our clock recovery algorithm, based on single photon clicks received from reference signal time multiplexed with the quantum states. With this technique, we achieve below nanosecond accuracy within less than a second.

Q 8: Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)

Time: Monday 17:00–19:00 Location: HS 1010

Q 8.1 Mon 17:00 HS 1010

Time-reversal in a quantum many-body spin system — •Sebastian Geier[1], Adrian Braemer[1,2], Eduard Braun[1], Maximilian Müllenbach[1], Titus Franz[1], Martin Gärttner[1,2,3], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Physikalisches Institut, Im Neuenheimer Feld 226 — [3]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Time reversal in a macroscopic system is contradicting daily experience. Yet, with the precise control capabilities provided by modern quantum technology, the unitary evolution of a quantum system can be reversed, rendering it a powerful tool for scientific discovery and technological advancements. Here, we implement a time-reversal protocol in a dipolar interacting many-body spin system represented by Rydberg states in an atomic gas. By changing the states encoding the spin, we flip the sign of the interaction Hamiltonian, and demonstrate the reversal of the relaxation dynamics of the magnetization by letting a demagnetized many-body state evolve back-in-time into a magnetized state. We elucidate the role of atomic motion using the concept of a Loschmidt echo. Finally, by combining the approach with Floquet engineering, we demonstrate time reversal for a large family of spin models with different symmetries. Our method of state transfer is applicable across a wide range of quantum simulation platforms and has applications far beyond quantum many-body physics.

Q 8.2 Mon 17:15 HS 1010

Exploring the vibrational series of pure trilobite Rydberg molecules — •Markus Exner, Max Althön, Richard Blättner, and Herwig Ott — RPTU Kaiserslautern-Landau, Kaiserslautern, Deutschland

We report on the observation of two vibrational series of pure trilobite rubidium Rydberg molecules. These kinds of molecules consist of a Rydberg atom and a ground state atom. The binding mechanism is based on the scattering interaction between the Rydberg electron and the ground state atom. The trilobite molecules are created via three-photon photoassociation and lie energetically more than 15 GHz below the atomic 22F state. In agreement with theoretical calculations, we find an almost perfect harmonic oscillator behavior of six vibrational states. We show that these states can be used to measure electron-atom scattering lengths for low energies in order to benchmark current theoretical calculations. The molecules have extreme properties: their dipole moments are in the range of kilo-Debye and the electronic wave function is made up of high angular momentum states with only little admixture from the nearby 22F state. This high-l character of the trilobite molecules leads to an enlarged lifetime as compared to the 22F atomic state. Furthermore, our ion pulse spectrometer provides insights into the decay processes.

Q 8.3 Mon 17:30 HS 1010

Green's function treatment of Rydberg molecules with spin — •Matthew Eiles[1] and Chris Greene[2] — [1]Max Planck Institut für Physik komplexer Systeme, Nöthnitzer Str 38, 01187 Dresden Germany — [2]Department of Physics and Astronomy and Purdue Quantum Science and Engineering Institute, Purdue University, West Lafayette, Indiana 47907, USA

The determination of ultra-long-range molecular potential curves has been reformulated using the Coulomb Green's function to give a solution in terms of the roots of an analytical determinantal equation. For a system consisting of one Rydberg atom with a fine structure and a neutral perturbing ground state atom with hyperfine structure, the solution yields potential energy curves and wave functions in terms of the quantum defects of the Rydberg atom and the electron-perturber scattering phase shifts and hyperfine splittings. This method provides a promising alternative to the standard currently utilized method of diagonalization, which suffers from problematic convergence issues and nonuniqueness, and can potentially yield a more quantitative relationship between Rydberg molecule spectroscopy and electron-atom scattering phase shifts.

Q 8.4 Mon 17:45 HS 1010

Rydberg Atomtronic Devices — •Philip Kitson[1,2], Tobias Haug[1], Antonino La Magna[3], Oliver Morsch[4], and Luigi Amico[1,2,5] — [1]Technology Innovation Institute, Abu Dhabi, UAE — [2]Dipartimento di Fisica e Astronomia and INFN-Sezione di Catania, Catania, Italy — [3]CNR-IMM, Catania, Italy — [4]CNR-INO, Pisa, Italy — [5]Centre for Quantum Technologies, Singapore

Atomtronics realises circuits through the guidance of neutral ultra-cold atoms. However, a recent proposal in the field of atomtronics has been the integration of Rydberg atoms, whereby instead of transporting matter, the established flow is of Rydberg excitations. We take advantage of the blockade and anti-blockade phenomena, resulting from the large dipole moments of such atoms, to prevent or facilitate the flow of excitations throughout networks of Rydberg atoms. In our work, we capitalise on these ideas along with the use of specific atom detunings, in order to create a toolbox of Atomtronics devices. We first formulate a method to control the flow of excitations through a Rydberg network via a detuning upon a gate atom as an analogy to a switch. Second, we generate non-reciprocal flow by using certain conditions of the anti-blockade (the gate atom's detuning and position). Lastly, we devise Rydberg networks to conduct logical decisions. Employing the anti-blockade mechanism we create a classical AND gate and a NOT gate, whereby combining both, we produce a universal logic gate set.

Q 8.5 Mon 18:00 HS 1010

Spectral signatures of vibronic coupling in trapped cold atomic Rydberg systems — •Joseph William Peter Wilkinson[1], Weibin Li[2], and Igor Lesanovsky[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Atoms and ions confined with electric and optical fields form the basis of many current quantum simulation and computing platforms. When excited to high-lying Rydberg states, long-ranged dipole interactions emerge which strongly couple the electronic and vibrational degrees of freedom through state-dependent forces. This vibronic coupling and the ensuing hybridization of internal and external degrees of freedom manifest through clear signatures in the many-body spectrum. In this talk, we briefly discuss the recent results in Ref. [1] wherein we consider the case of two trapped Rydberg ions that realize a quantum Rabi model due to the interaction between the relative vibrations and Rydberg states. We proceed to demonstrate that this hybridization can be probed by radio frequency spectroscopy and discuss observable spectral signatures at finite temperatures and for larger ion crystals.

[1]. J. W. P. Wilkinson, W. Li, and I. Lesanovsky, *Spectral signatures of vibronic coupling in trapped cold atomic Rydberg systems*, arXiv:2311.16998 (2023)

Q 8.6 Mon 18:15 HS 1010

Avalanche terahertz photon detection in a Rydberg tweezer array — •Chris Nill[1,2], Albert Cabot[1], Arno Trautmann[3], Christian Gross[3], and Igor Lesanovsky[1,4] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Institute for Applied Physics, University of Bonn, Wegelerstraße 8, 53115 Bonn, Germany — [3]Physikalisches Institut, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [4]School of Physics and Astronomy, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We propose a protocol for the amplified detection of low-intensity terahertz radiation using Rydberg tweezer arrays [1]. The protocol offers single photon sensitivity together with a low dark count rate. It is split into two phases: during a sensing phase, it harnesses strong terahertz-range transitions between highly excited Rydberg states to capture individual terahertz photons. During an amplification phase, it exploits the Rydberg facilitation mechanism which converts a single terahertz photon into a substantial signal of Rydberg excitations. We discuss a concrete realization based on realistic atomic interaction parameters, develop a comprehensive theoretical model that incorporates the motion of trapped atoms, and study the many-body dynamics using tensor network methods.

[1] C. Nill et al., Avalanche terahertz photon detection in a Rydberg tweezer array, arXiv:2311.16365 (2023).

Q 8.7 Mon 18:30 HS 1010

Ultrafast excitation of dense Rydberg gases at the threshold to ultracold plasma — •Jette Heyer[1,2], Mario Grossmann[1,2], Julian Fiedler[1,2], Markus Drescher[1,2], Klaus Sengstock[1,2], Philipp Wessels-Staarmann[1,2], and Juliette Simonet[1,2] — [1]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [2]Center for Optical Quantum Technologies, University of Hamburg, Hamburg, Germany

Ultrashort laser pulses enable the local ionization of a quantum gas on femtosecond time scales. By tuning the central wavelength of a single laser pulse of 166 fs duration across the two-photon ionization threshold of ^{87}Rb, we investigate the transition from ultracold plasma to dense Rydberg gases.

Above this threshold, strong-field ionization triggers the formation of a highly charged ultracold plasma. Below the ionization threshold, we observe the ultrafast formation of dense Rydberg gases as the Rydberg blockade is bypassed by the large bandwidth of the femtosecond pulse. Charge-imbalanced microplasma dynamics prevent Rydberg recombination close to the threshold and leads to ionization of deeply bound Rydberg states even far below the threshold.

Our experimental setup allows us to directly detect the energy distribution of ions and electrons as well as Rydberg atoms. State of the art molecular dynamics simulations give us insight into the underlying dynamics of the many-body system, which is governed by long-range Coulomb interactions.

Q 8.8 Mon 18:45 HS 1010

Toward the demonstration of an avalanche THz photon detector with Rydberg atoms — •Fabio Bensch, Lea-Marina Steinert, Philip Osterholz, Shuanghong Tang, Arno Trautmann, and Christian Gross — Eberhard Karls Universität, Tübingen, Germany

Rydberg atoms confined within tweezers demonstrate unique capabilities in realizing strongly interacting and correlated many-body phenomena. The anti-blockade effect, notably, has proven to be an optimal tool for controlling non-linear avalanche Rydberg excitation in both disordered and ordered many-body systems. The integration of optical tweezers with advanced sorting algorithms enables the creation of defect-free arrays with highly precise geometry. In this context, we introduce a novel approach where the combination of defect-free arrays and avalanche facilitated excitation yields a straightforward and fuctional THz photon detector. This opens up an innovative utilization of Rydberg atoms to address the challenging issue of THz photon detection.

Q 9: Bosonic Quantum Gases II (joint session Q/A)

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

Q 9.1 Mon 17:00 Aula

Regression theorem and nonlinear response in a photon Bose-Einstein condensate — Alexander Sazhin[1], Vladimir N. Gladilin[2], Andris Erglis[3], Frank Vewinger[1], Martin Weitz[1], Michiel Wouters[2], and •Julian Schmitt[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]TQC, Universiteit Antwerpen, Universiteitsplein 1, B-2610 Antwerpen, Belgium — [3]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

The quantum regression theorem states that the correlations of a system at two different times are governed by the same equations of motion as the temporal response of the average values. Here we report experiments demonstrating that the two-time second-order correlations of a photon Bose-Einstein condensate inside a dye-filled microcavity exhibit the same eigenvalues of the dynamics as the response of the condensate to a sudden perturbation of the dye molecule bath. This confirms an unconventional form of the regression theorem for a coupled many-body quantum system, where the perturbation acts on the bath and only the condensate response is monitored. For strong perturbations, we observe nonlinear relaxation dynamics well described by microscopic theory, confirming the regression theorem for an optical quantum gas also beyond the regime of linear response.

Q 9.2 Mon 17:15 Aula

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

Open quantum many-body systems interacting with their environment can reach interesting non-equilibrium steady states. We want to describe a quantum gas mixture theoretically in the framework of open systems in order to use it for dissipative quantum simulations. We consider a mixture of ultracold atoms of two different species, treating one as the system and the other as the bath, both weakly interacting via contact interaction. The specific model system describes atoms trapped in a one-dimensional optical lattice which is immersed in the cloud of bath atoms. Due to species-selective potentials it is possible that the bath atoms are uneffected by the lattice potential and freely evolve and interact with the system atoms. The bath is treated as an ideal fermionic/bosonic quantum gas. Starting from a microscopic model, we define a spectral coupling density within the Born-Markov approximation scheme and compare it with a simple ansatz describing a local ohmic bath, which is often used in this scenario.

Q 9.3 Mon 17:30 Aula

A Coherence Microscope Based on the Matter-Wave Talbot Effect — •Justus Brüggenjürgen, Mathis Fischer, and Christof Weitenberg — Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Imaging is crucial for gaining insight into physical systems. In the case of ultracold atoms in optical lattices, quantum gas microscopes have revolutionized the access to quantum many-body systems by detecting and addressing single atoms on single lattice sites. The novel technique of quantum gas magnification uses matter-wave optics to magnify the density distribution before the optical imaging and therefore allows to directly image the Talbot carpet that forms when releasing the atoms from an optical lattice.

We realize this for a BEC of Lithium-7 atoms in a triangular optical lattice and map out the spatial coherence by analyzing the contrast of successive Talbot copies. The technique should also allow to reconstruct the fluctuating phase profile of individual samples imaged at a Talbot copy. This will realize a coherence microscope with spatially resolved access to phase information, which allows to study domain walls, thermally activated vortex-pairs, or to locally evaluate coherence in inhomogeneous quantum many-body systems.

Q 9.4 Mon 17:45 Aula

An Optical Quantum Gas Magnifier for Lithium-7 Atoms — •Mathis Fischer, Justus Brüggenjürgen, and Christof Weitenberg — Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Ultracold gases in optical lattices are a pristine experimental platform for quantum simulation of complex many-body systems as they come with a high degree of control and a wide range of accessible observables. The advent of quantum gas microscopes has revolutionized the access to quantum many-body systems by detecting and addressing single particles on single lattice sites. The novel complementary approach of quantum gas magnification expands this toolbox to 3D systems and large occupation numbers. Here the atomic density distribution is magnified via matter-wave optics before taking absorption images with effective sub-lattice site resolution.

We report on the realization of an all-optical quantum gas magnifier for ultracold Lithium-7 atoms in triangular optical lattices i.e. using an optical dipole trap as matter-wave lens. The all-optical approach allows us to exploit the broad Feshbach resonance of Lithium to control the interaction strength. With this technique, we can access the coherence properties of the system. In the future, the optical matter-wave lens will also allow to image spin mixtures. Furthermore, the addition of high numerical aperture optics will allow for single-atom sensitivity via free-space fluorescence imaging.

Q 9.5 Mon 18:00 Aula

Site-resolved current and kinetic energy measurements using optical superlattices — •Alexander Impertro[1,2,3], Simon Karch[1,2,3], Julian Wienand[1,2,3], SeungJung Huh[1,2,3], Christian Schweizer[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2,3] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Schellingstr. 4, D-80799 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80333 Munich — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, D-85748 Garching, Germany

Quantum gas microscopes naturally realize a measurement of the particle number density in an optical lattice. Further information about the underlying quantum state can only be obtained by measuring additional, complementary observables. Here, we demonstrate how optical superlattice potentials can be used to measure the expectation values of the current and the kinetic energy operator. Our scheme is based on driving programmable rotations in isolated double wells to rotate the measurement basis in an arbitrary direction. Furthermore, we show that a local control enables to perform spatially varying rotations, which can be used both to read out complex correlators as well as to engineer interesting quantum states. The presented scheme will pave the way for a more flexible state tomography and state engineering in optical lattices, and in particular to detect exotic quantum many-body phases that have no signatures in the density.

Q 9.6 Mon 18:15 Aula

Interplay of topology and disorder in driven honeycomb lattices — •Johannes Arceri[1,2,3], Alexander Hesse[1,2,3], Christoph Braun[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, München — [2]Munich Center for Quantum Science and Technology (MCQST), München — [3]Max-Planck-Institut für Quantenoptik, Garching

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

Our experimental platform involves bosonic atoms in a periodically-driven honeycomb lattice. Depending on the driving parameters, several out-of-equilibrium topological phases can be realized, among which an anomalous phase.

Chiral edge modes can be probed by releasing an atomic wavepacket from a tightly focused optical tweezer in proximity of the potential step projected by a digital micromirror device. The additional projection of an optical speckle potential on the honeycomb lattice allows for the realization of disordered systems. We benchmark the robustness of edge modes to disorder across different topological regimes and observe a disorder-driven transition from the Haldane regime to the anomalous regime. Furthermore, we compare edge state dynamics to the expansion of bulk states for increasing disorder strength.

Q 9.7 Mon 18:30 Aula

Quantum geometry of bosonic Bogoliubov quasiparticles — •Isaac Tesfaye and André Eckardt — Institut für Theoretische Physik, Technische Universität Berlin Hardenbergstraße 36, 10623 Berlin, Germany

Topological and geometrical features arising bosonic Bogoliubov-de Gennes (BdG) systems have mainly been studied by utilizing a symplectic (generalized) version of the Berry curvature and Chern number. These bosonic topological features may even solely arise due to the non-particle number conserving terms in the corresponding BdG Hamiltonian, making these systems inherently distinct from their non-interacting (fermionic) counterparts. Here, we propose the notion of the symplectic quantum geometric tensor (SQGT) whose imaginary part leads to the previously studied symplectic Berry curvature, while the real part gives rise to a symplectic quantum metric, providing a natural distance measure in the space of bosonic Bogoliubov modes. Moreover, previous proposals to verify the topology of bosonic BdG systems have relied solely on probing topologically protected chiral edge modes. Here, we propose how to measure all components of the SQGT by the use of periodic modulation of the systems' parameters in a linear response regime and connect the symplectic Berry curvature to a generalized anomalous velocity term for Bogoliubov Bloch wave packets.

[1] R. Shindou et al., Phys. Rev. B 87, 174427 (2013).
[2] S. Furukawa and M. Ueda, New J. Phys. 17, 115014 (2015).
[3] T. Ozawa and N. Goldman, Phys. Rev. B 97, 201117 (2018).

Q 9.8 Mon 18:45 Aula

Dressed 171Yb+ Hyperfine Qubits in a Multi-layer Planar Ion Trap — •Elham Esteki[1], Bogdan Okhrimenko[1], Amado Bautista Salvador[2,3,4], Christian Ospelkaus[2,3,4], Ivan Boldin[1], and Christof Wunderlich[1] — [1]Dept. Physik, Nat.-Techn. Fak., Universität Siegen, 57068 Siegen (Germany) — [2]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover (Germany) — [3]Laboratory for Nano - and Quantum Engineering, Schneiderberg 39, 30167 Hannover (Germany) — [4]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig (Germany)

Dressed atomic states - the eigenstates of the Hamiltonian of an atom subject to a near-resonant driving field - protect atomic states against decoherence due to common noise sources. We present a microfabricated ion-trap-chip, designed for quantum information processing based on radiofrequency-dressed qubits using hyperfine states of 171Yb+ ions [1]. The trap-chip consists of multiple layers [2], one of which includes an integrated RF resonator near 12.6 GHz. It creates an axial gradient of the microwave magnetic field amplitude which serves for individual qubit addressing, as well as for qubit-qubit coupling. We experimentally characterize this novel ion-trap-chip and demonstrate preparation, manipulation and detection of RF-dressed single-and two-qubit gates.

References
1. S. Wölk et al., New J. Phys. 19, 083021 (2017)
2. A. Bautista-Salvador et al., New J. Phys. 21, 043011 (2019)

Q 10: Cavity QED

Time: Monday 17:00–19:00 Location: HS 1199

Invited Talk Q 10.1 Mon 17:00 HS 1199

Correlated light-matter states from first principles and their use for chirality, and chemistry — •Christian Schäfer — Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden.

Confining optical or plasmonic modes results in a strong increase in light-matter coupling and leads to the creation of hybrid light-matter states, called polaritons. Control over the electromagnetic confinement allows, therefore, to non-intrusively control the correlated eigenstates. Here, we focus on two fascinating applications that emerge from this realization. First, breaking chiral symmetry with specifically designed electromagnetic environments paves the way for a new direction in chiral recognition [1,2]. Second, we refine our theoretical tool-box and investigate how vibrational strong coupling can control chemical reactivity [3-7]. We conclude with an outlook on active research addressing plasmonic catalysis and the quantization and treatment of macroscopic open quantum-systems.

[1] C. Schäfer, D. Baranov, J. Phys. Chem. Lett. 2023, 14, 15, 3777-3784. [2] D. Baranov, C. Schäfer, M. Gorkunov, ACS Photonics 2023, 10, 8, 2440-2455. [3] C. Schäfer, Phys. Chem. Lett. 2022, 13, 30, 6905-6911. [4] C. Schäfer, F. Buchholz, M. Penz, M. Ruggenthaler, and A. Rubio, PNAS 2021 Vol. 118 No. 41 e2110464118. [5] C. Schäfer, J. Flick, E. Ronca, P. Narang, and A. Rubio, Nature Communications, (2022) 13:7817. [6] C. Schäfer, J. Fojt, E. Lindgren, and P. Erhart, arXiv:2311.09739, (2023). [7] M. Castagnola, T. Haugland, E. Ronca, H. Koch, C. Schäfer, to be submitted (2023).

Q 10.2 Mon 17:30 HS 1199

Microcavity-mediated coupling of two molecules — •Jahangir Nobakht[1,2], André Pscherer[1,2], Jan Renger[1], Tobias Utikal[1], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, D-91058, Germany. — [2]Department of Physics, Friedrich-Alexander University, Erlangen, D-91058, Germany.

We have successfully established efficient coupling between two individual organic molecules by harnessing their strong coupling to a Fabry-Perot microcavity, thereby realizing the Tavis-Cummings model with dual emitters. This achievement is marked by the collective enhancement of the vacuum Rabi splitting, accompanied by the emergence of a distinctive dark middle peak. Our investigation further unveils the formation of subradiant/superradiant states within the dispersive regime of cavity quantum electrodynamics (QED), accompanied by a collectively enhanced Lamb shift in the superradiant state. Our work demonstrates the potential for achieving a high density of solid-state emitters with high individual cooperativity. This capability opens avenues for detecting rich, long range, coherent multi-photon intermolecular processes.

Q 10.3 Mon 17:45 HS 1199

Cavity Polaritons Formation at the Gap Edge of a Quantum Material — •Igor Gianardi[1], Michele Pini[1], and Francesco Piazza[1,2] — [1]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [2]Institute of Physics, Universität Augsburg, 86159 Augsburg, Germany

Quantum nonlinear optics is a rapidly expanding field, which offers significant technological potential while engaging with intricate and novel many-body phenomena. This area of research delves into optical nonlinearities arising from the interactions between polaritons, hybrid quasi-particles which blend matter and light properties. The formation and interaction of polaritons, while having been extensively studied in various atomic platforms, remain largely unexplored in the realm of quantum materials, where the influence of strong electron correlations is particularly significant [1-3]. Our research concentrates on materials that exhibit an ordered gapped phase, introducing a novel type of polariton. This polariton is characterized by the hybridization of a cavity photon and a specific electronic interband excitation. As a paradigmatic example we consider CDW-insulators. Our findings reveal that polaritons located slightly below the energy gap display remarkably large dispersion while exhibiting zero absorption. The distinctive properties of these polaritons hint that their interactions will manifest highly pronounced nonlinearities.

[1] M. Kiffner et al., New J. Phys. 21, 073066 (2019)
[2] A. Allocca et al., Phys. Rev. B 99, 020504(R) (2019)
[3] L. B. Tan et al., Phys. Rev. X 10, 021011 (2020)

Q 10.4 Mon 18:00 HS 1199

Cavity-mediated collective emission from few emitters in a diamond membrane — •Kerim Köster[1], Maximilian Pallmann[1], Yuan Zhang[2], Julia Heupel[3], Timon Eichhorn[1], Cyril Popov[3], Klaus Mølmer[4], and David Hunger[1] — [1]Karlsruhe Institute of Technology, Germany — [2]Zhengzhou University, China — [3]University of Kassel, Germany — [4]University of Copenhagen, Denmark

When an ensemble of quantum emitters couples to a common radiation field, their polarizations can synchronize and a collective emission termed superfluorescence can occur. Entering this regime in a free-space setting requires a large number of emitters with a high spatial density as well as coherent optical transitions with small inhomogeneity. Here we show that by coupling nitrogen-vacancy (NV) centers in a diamond membrane to a high-finesse microcavity, also few, incoherent, inhomogeneous, and spatially separated emitters - as are typical for solid state systems - can enter the regime of collective emission. We observe a super-linear power dependence of the emission rate as a hallmark of collective emission. Furthermore, we find simultaneous photon bunching and antibunching on different timescales in the second-order auto-correlation function, revealing cavity-induced interference in the quantized emission from about fifteen emitters. We develop theoretical models and find that the population of collective states together with cavity enhancement and filtering can explain the observations. Such a system has prospects for the generation of multi-photon quantum states, and for the preparation of entanglement in few-emitter systems. Related publication: arXiv:2311.12723v1

Q 10.5 Mon 18:15 HS 1199

Ultrafast Excitation Exchange in a Maxwell-Fish-Eye Lens — •Oliver Diekmann, Dmitry O. Krimer, and Stefan Rotter — Institute for Theoretical Physics, TU Wien, Vienna A-1040, Austria

The strong coupling of quantum emitters to a cavity mode has been of paramount importance in the development of quantum optics. Recently, also the strong coupling to more than a single mode of an electromagnetic resonator has drawn considerable interest. We investigate how this multimode strong coupling regime can be harnessed to coherently control quantum systems. Specifically, we demonstrate that a Maxwell-Fish-Eye lens can be used to implement a pulsed excitation-exchange between two distant quantum emitters. This periodic exchange is mediated by single-photon pulses and can be extended to a photon-exchange between two atomic ensembles, for which the coupling strength is enhanced collectively.

Q 10.6 Mon 18:30 HS 1199

Jaynes-Cummings Model for Chiral Cavity Quantum Electrodynamics — •Lara Marie Tomasch, Stefan Yoshi Buhmann, and Fabian Spallek — Universität Kassel

We examine the effects of chirality on the interaction of a two-level quantum system with a single mode of the quantised electrcomagnetic field inside a cavity. Considering chiral standing waves inside a cavity and a chiral two-level molecule, we develop a generalised Jaynes-Cummings model and study its modified coupling constants and Rabi oscillations. Our results imply an increase of coupling for matching handedness of the field and molecule.

Q 10.7 Mon 18:45 HS 1199

Position-resolved pseudomode description of open cavities — •Lucas Weitzel, Andreas Buchleitner, and Dominik Lentrodt — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

A wide-spread quantum optical method to describe light matter interaction consists in reducing the involved degrees of freedom to the absolute minimum, such as those of a two-level atom (strongly) coupled to an isolated mode of a cavity. All other degrees of freedom are thus screened away as an "environment" which couples only weakly to the hybrid. Such separation is derived from first principles in many textbook scenarios, and allows an efficient description of the dynamics e.g. by Markovian Lindblad master equations. The system-environment separation becomes ever more difficult, though, as the number of strongly coupled degrees of freedom increases, e.g. for a two-level atom in a low-quality cavity where resonator modes may overlap or even drown in a continuum background. Given the mathematically well-controlled framework of Markovian Lindblad master equations, it is important to understand under which conditions the emerging dynamics can still be understood as resulting from an effective interaction of the atom with a set of broadened modes (pseudomodes), over a weakly coupled environment. To settle this question, we construct a fully analytical pseudomode representation of open cavities through "reverse-engineering" from the position-resolved atomic dynamics within the cavity. We discuss the versatility of our method and potential applications to more complex atomic (or molecular) targets.

Q 11: Precision Measurements I (joint session Q/A)

Time: Monday 17:00–19:00 Location: HS 1221

Q 11.1 Mon 17:00 HS 1221

Search for variations of fundamental constants with highly charged ion clocks — •Luis Hellmich[1,2], Ullrich Schwanke[1,2], Steven Worm[1,2], and Lakshmi Kozhiparambil Sajith[2,3] — [1]Humboldt-Universität Berlin — [2]DESY Zeuthen — [3]MPIK Heidelberg

The measurement of the variation of fundamental constants would be strong evidence for new physics. In particular, many different theories predict the variation the fine-structure constant α. Atomic clocks are a highly precise tool of measuring variations of α, as the clock transitions may change with α.

We are aiming to compare a Sr-lattice clock as a reference to a highly charged ion (HCI) clock. HCI clocks are expected to have extremely high sensitivities to α-variations. We show how such a setup could set new limits on variations of fundamental constants. Furthermore, we estimate with Monte-Carlo simulations and real data how those limits translate to constraints on scalar dark matter models and models with Lorentz-invariance violation.

Q 11.2 Mon 17:15 HS 1221

A strontium optical clock based on Ramsey-Bordé spectroscopy — •Amir Mahdian[1], Oliver Fartmann[1], Ingmari C Tietje[1], Martin Jutisz[1], Conrad L Zimmermann[2], Vladimir Schkolnik[1,2], Marc Christ[2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We are developing a Ramsey-Bordé based optical atomic clock where the long-term stability relies on interrogating a stream of strontium atoms. Our choice of the clock transition is the $5s^2\ {}^1S_0 \rightarrow 5s5p\ {}^3P_1$ intercombination line of Sr at 689 nm, targeting an Allan deviation as low as 2×10^{-15} between 100 s and 1000 s, and 10^{-15} for longer interogation times.

Following an overview of our atom interferometer's current status, the latest developments in the power and frequency stability of the relevant lasers and a different readout mechanism will be presented. Additionally, I showcase the observation of Ramsey-Bordé fringes, accompanied by numerical simulations to aid in interpreting the signal. Moreover, I discuss the stability comparison of our atomic beam clock vs a Rb two-photon frequency reference.

This work is supported by the German Space Agency (DLR), with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant number DLR50WM1852, and by the German Federal Ministry of Education and Research (BMBF) within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 11.3 Mon 17:30 HS 1221

Electronic Bridge schemes in ^{229}Th doped LiCAF — •Tobias Kirschbaum[1], Martin Pimon[2], and Adriana Pálffy[1] — [1]Julius-Maximilians-Universität Würzburg, Germany — [2]Technische Universität Wien, Austria

Large band gap crystals such as CaF_2 or $LiCaAlF_6$ (LiCAF) are an ideal inert host for the nuclear clock candidate ^{229}Th. Among others, these crystals are transparent with respect to the clock transition at ≈ 8 eV and a large number of nuclei can be interrogated at the same time [1]. However, DFT calculations indicate that doping of ^{229}Th in these crystals leads to the formation of localized electronic states in the band gap, so-called defect states [2]. Due to their vicinity to the nuclear transition energy, these can be used for effective nuclear excitation via the Electronic Bridge mechanism, as we could show for the case of Th-doped CaF_2 crystals [2,3].

Here, we investigate theoretically different driven Electronic Bridge schemes for ^{229}Th doped LiCAF crystals and present the corresponding excitation rates. These schemes enable a more efficient nuclear excitation/deexcitation compared to direct photoexcitation. The results are discussed in conjuncture with the design of a solid-state nuclear clock.

[1] G. A. Kazakov *et al.*, New J. Phys. **14**, 083019 (2012).
[2] B. S. Nickerson *et al.*, Phys. Rev. Lett **125**, 032501 (2020).
[3] B. S. Nickerson *et al.*, Phys. Rev. A **103**, 053120 (2021).

Q 11.4 Mon 17:45 HS 1221

Large ring lasers in geodesy and seismology — •Simon Stellmer[1], Jannik Zenner[1], Andreas Brotzer[2], Jan Kodet[3], Heiner Igel[2], and Karl Ulrich Schreiber[3] — [1]Universität Bonn — [2]LMU München — [3]Geodätisches Observatorium Wettzell und TU München

The rotation of Earth is not as constant as it may seem. On the contrary, it is modulated through various processes at a large range of frequencies. Traditionally, these variations are measured by astronomical techniques such as VLBI, but there is a new kid on the block: large ring lasers have matured to a level that allows for continuous monitoring of variations in the Earth rotation rate at the level of 10^{-8} and below. We will give an overview on the three large ring lasers currently operated in Germany, latest advances and technology development, as well as applications and future perspectives.

Q 11.5 Mon 18:00 HS 1221

Quantum Memory Enhanced Velocimetry — •Yagiz Murat[1], Arash Ahmadi[1], Mustafa Gündoğan[1], and Markus Krtutzik[1,2] — [1]Humboldt Universität zu Berlin, Institut für Physik — [2]The Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik

Optical interferometry is crucial in motion sensing. Recent progress has utilized electromagnetically induced transparency (EIT) to measure the velocity of a moving medium, leveraging Fizeau's light-dragging effect. This novel approach opens new possibilities for quantum optical methods in velocimetry, Our work is centered around EIT-based quantum memories. Light storage is realized by tuning a probe and a control field to the Zeeman-split levels of the D1 transition line of cesium atoms ($F = 4 \rightarrow F' = 3$). By monitoring the phase difference of the beating signal of the probe field with a reference field, before and after storage of the probe field, displacement of the cesium vapor cell can be measured down to the nanometer scale. This work contributes to the frontiers of quantum optics and motion sensing, promising advancements in precision measurements. This work has been funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under grant number 448245255.

Q 11.6 Mon 18:15 HS 1221

Suppression of scattered light through tunable coherence in Sagnac-Speed-Meters — •Leonie Eggers, Daniel Voigt, and Oliver Gerberding — Universität Hamburg, Institut für Experimentalphysik, Germany

As scattered light noise is a dominating limitation for the sensitivity of gravitational wave detectors, we investigate the use of tunable coherence as a new concept to suppress scattered light.

Tunable coherence is realised by phase modulation following a pseudo-random sequence, which artificially shortens the coherence length of stable continuous wave lasers to the centimeter scale. While Sagnac-Speed-Meter topologies provide a potential alternative for the currently used Michelson-interferometers for future gravitational wave detectors, they suffer from the same limitations through scattered light, as well as the effect of light backscattering from the mirrors and coupling into the counter-propagating beam. We are investigating the use of tunable coherence in Sagnac-Speed-Meters to suppress scattered light through simulations and a tabletop experiment. We are presenting our recent findings on using tunable coherence in Sagnac-Speed-Meters.

Q 11.7 Mon 18:30 HS 1221

Investigating a Tensegrity structure as a possible multi DoF inertial sensor — •Ben Becker, Oliver Gerberding, and Artem Basalaev — IExP, Hamburg, Germany

One of the continued challenges for gravitational wave detectors is the advancement of inertial sensors to improve the active isolation of the mirrors. Towards that end we are investigating tensegrity structures as a possible multi degree of freedom inertial sensor. Tensegrity structures are disconnected multi body structures held together by tensioned wires. They offer the option of tuning their mechanical properties by changing the moment of inertial as well as the wire tension. We've simulated a model tensegrity using Ansys multibody dynamics and analyzed its mechanical response to excitation. We compare the direct simulation result with the results of a simulated readout scheme. This readout scheme will be realized on a real tensegrity model for further comparison. We've observed and fitted the transfer functions of the system to get a more thorough understanding with regards to its invertibility and thermal noise. The tensegrity shows distinct transfer function with regimes of linear response for most relevant degrees of freedom. Therefore it should indeed be viable as an inertial sensor.

Q 11.8 Mon 18:45 HS 1221

Full spatio-temporal description of Non-linear interference based on cascaded Spontaneous Parametric Down-Conversion. — •Carlos Sevilla[1,2], Purujit Chauhan[1,2], and Fabian Steinlechner[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany — [2]Abbe Center of Photonics, Friedrich-Schiller-University Jena, Albert-Einstein-Str. 6, 07745 Jena, Germany

Non-linear interferometers are a powerful tool for quantum state engineering and applications in quantum sensing with enhanced phase sensitivity [1]. The typical configuration uses a cascade of non-linear processes such as spontaneous parametric down-conversion (SPDC) combined with spatial or spectral dispersion. This architecture has been widely used, but only few studies have addressed the complete spatiotemporal correlations of the output state of a nonlinear interferometer. Here we extend our results on the spatiotemporal description of SPDC based on the spectral dependence of Laguerre-Gauss modes [2] to the output spatio-temporal state of nonlinear interferometers. For this, we take into consideration realistic parameters such as phase difference between the three fields, the optical system which might induce spatial transformation, and polarization rotations inside then nonlinear interferometer. Furthermore, we show experimental results validating our predictions. References:[1] Bernard Yurke et al. Phys. Rev. A 33, 4033 (1986). [2] A. Ferreri et al. Quantum 5,461 (2021). [3] C. Sevilla-Gutiérrez, et.al. Spectral Properties of Transverse Laguerre-Gauss Modes in Parametric Down-Conversion. arXiv:2209.01913

Q 12: Quantum Communication II

Time: Monday 17:00–19:00 Location: HS 3118

Q 12.1 Mon 17:00 HS 3118

Ensemble based quantum protocol for ultra save quantum money — •Bernd Bauerhenne[1], Malwin Xibraku[1], Boris Naydenov[2], Cyril Popov[1], Martin Garcia[1], and Kilian Singer[1] — [1]Universität Kassel, Heinrich-Plett Straße 40, 34132 Kassel — [2]Helmholtz-Zentrum Berlin

We present a ensemble based quantum token protocol [1,2] that can detect counterfeiting by analysing the measurement noise. A quantum token consists now of identical qubits. Each quantum token is prepared by a bank by writing all qubits into the same state. The angles are kept secret. Multiple ensemble-based quantum tokens will have different secret states. During verification, the bank measures the qubits of the quantum token with the secret angles and if more than a given critical number of qubits are projected into the ground state, the quantum token is accepted. If from the set of quantum tokens more than a given number of quantum token is accepted, the whole set is accepted. We discuss how big the probability is that the bank accepts the counterfeit tokens. We show how resources must be scaled such that the probability that the bank accepts a counterfeit token set becomes arbitrary small.

[1] https://www.forschung-it-sicherheit-kommunikationssysteme.de/projekte/diqtok
[2] K. Singer, C. Popov, B. Naydenov, Verfahren zum Erstellen eines Quanten-Datentokens (DE 10 2022 107 528 A1) DE-Patent (2023)

Q 12.2 Mon 17:15 HS 3118

Robust Preparation of Ensemble-based Quantum Tokens with Trapped Ions — •Manika Bhardwaj, Jan Thieme, Bernd Bauerhenne, Moritz Göb, Bo Deng, and Kilian Singer — Institut für Physik, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

Quantum tokens are an important building block for securing identification devices. Previous implementations were based on the quantum no-cloning theorem. Here we present a novel quantum token protocol [1] and its implementation with an ensemble of trapped ions. Due to long coherence times and single-shot readout, trapped ions are well-suited for implementing a robust quantum token protocol. We aim to implement the quantum token protocol on the $4^2S_{1/2} - 3^2D_{5/2}$ transition of $^{40}Ca^+$ ions. Uniform preparation of the entire ensemble of trapped ions is crucial for the protocol because errors directly influence the security of the quantum token protocol. We will present adapted composite pulses [2, 3] that address different resonance frequencies and are robust against intensity-based pulse area errors of the individual ions. [1] K. Singer, C. Popov, and B. Naydenov, Verfahren zum Erstellen eines Quanten-Datentokens (DE 10 2022 107 528 A1) DE-Patent (2023). [2] B. T. Torosov, S. S. Ivanov, and N. V. Vitanov, Narrowband and passband composite pulses for variable rotations, Phys. Rev. A 102, 013105 (2020). [3] G. T. Genov, M. Hain, N. V. Vitanov, and T. Halfmann, Universal composite pulses for efficient population inversion with an arbitrary excitation profile, Phys. Rev. A 101, 013827 (2020).

Q 12.3 Mon 17:30 HS 3118

A Photonic-Integrated Quantum-Random Number Generator — •Ömer Bayraktar[1,2], Jonas Pudelko[1,2], Christoph Pacher[3], Winfried Boxleitner[3], and Christoph Marquardt[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Max Planck Insitute for the Science of Light, Erlangen, Germany — [3]AIT Austrian Institute of Technology GmbH, Center for Digital Safety & Security, Vienna, Austria

A quantum-random number generator (QRNG) is a key componenent for quantum-key distribution systems. In addition, compared to conventional true-random number generators, it offers advantages in generation rate and modelling of the entropy source.

We present an experimental QRNG based on balanced homodyne detection of the quantum-optical vacuum state. This QRNG can also be operated under the restrictive requirements of a CubeSat.

The optical part of the QRNG is monolithically integrated on an Indium-Phosphide photonic-integrated circuit and is placed on a 10x10 cm^2 printed-circuit board accomodating necessary electronics. We show first conclusive results obtained with this system and discuss its operation in space.

Q 12.4 Mon 17:45 HS 3118

Tailored composite pulses for NV-colour centres towards the realization of ensemble based quantum tokens — •Jan Thieme, Josselin Bernardoff, Ricky-Joe Plate, Bernd Bauerhenne, and Kilian Singer — Universität Kassel, Kassel, Germany

We present numerical and experimental results of the application of tailored composite pulses [1] to robustly address ensembles of nitrogen-vacancy colour centres used in a novel protocol for quantum tokens [2,3]. By using analytical methods applied to the Rosen-Zener excitation model [4], we derive excitation profiles for a broadband excitation profile with respect to detuning and pulse duration to compensate for experimental deviations of resonance frequencies and pulse area in the quantum token. Towards this goal we are using an arbitrary waveform generator to supply these pulses to single nitrogen-vacancy colour centres [5]. In the outlook we will describe how this scheme can be improved to suppress sensitivity to technical limitations [6].

[1] B. T. Torosov and N. V. Vitanov, Phys. Rev. A 83, 053420 (2011). [2] https://www.forschung-it-sicherheit-kommunikationssysteme.de/projekte/diqtok [3] K. Singer, C. Popov, B. Naydenov, Verfahren zum Erstellen eines Quanten-Datentokens (DE 10 2022 107 528 A1) DE-Patent (2023) [4] N. Rosen and C. Zener, Phys. Rev. 40, 502 (1932). [5] A. Schmidt, J. Bernardoff, K. Singer, J. P. Reithmaier and C. Popov, Physica Status Solidi A, 216, 1900233 (2019). [6] G. T. Genov, M. Hain, N. V. Vitanov, and T. Halfmann, Phys. Rev. A, 101, 013827(2020).

Q 12.5 Mon 18:00 HS 3118

Nonlinear Quantum Photonics with a Tin-Vacancy Center Coupled to a Diamond Waveguide — Matteo Pasini, Nina Codreanu, •Tim Turan, Adria Riera Moral, Christian F. Primavera, Lorenzo De Santis, Hans K. C. Beukers, Julia M. Brevoord, Christopher Waas, Johannes Borregaard, and Ronald Hanson — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, PO Box 5046, 2600 GA Delft, The Netherlands

Color-centers integrated with nanophotonic devices have emerged as a compelling platform for quantum science and technology. Here we integrate tin-vacancy centers in a fiber-coupled diamond waveguide and investigate the interaction with light at the single-photon level. We observe single-emitter-induced extinction of the transmitted light up to 25% and measure the nonlinear effect on the photon statistics.

With this system, we demonstrate fully tunable interference between the reflected single-photon field and laser light back-scattered at the fiber end. The reflected field shows a corresponding change between bunched and anti-bunched photon statistics. Furthermore, we comment on progress towards using tin-vacancy centers in diamond waveguides as efficient quantum network nodes.

Q 12.6 Mon 18:15 HS 3118

Microwave control of the Tin-Vacancy center using magnetic field alignment — •Jeremias Resch[1], Ioannis Karapatzakis[1], Marcel Schrodin[1], Luis Kussi[1], Philipp Fuchs[2], Michael Kieschnick[3], Jan Meijer[3], Christoph Becher[2], Wolfgang Wernsdorfer[1], and David Hunger[1] — [1]Karlsruher Institut für Technologie, DE — [2]Universität des Saarlandes, DE — [3]Universität Leipzig, DE

Scalable quantum information processing requires spectrally stable interfaces between photons and solid-state qubits. Group-IV color centers exhibit an inversion symmetry protecting them from surface charge noise. By an optimized spectroscopy method, we identify hour-long charge-state and spectrally stable SnV centers with Fourier-limited optical linewidth using resonant excitation. To control the electron spin with high fidelity, the use of microwave fields is required. However, the magnetic transitions are heavily suppressed in unstrained emitters. This limitation can be circumvented by using naturally strained [1] or strain-engineered [2] SnV centers. Alternatively, a precise alignment of the DC magnetic field orientation allows for manipulation of the electron spin using microwave fields even at lower strain values. Hence, we implement a 3D vector magnet in a confocal microscope setup at mK temperatures. By aligning the DC magnetic field with respect to the SnV symmetry axis, we determine the angle dependent splitting of the electron spin ground and excited state and show the full fit to the SnV electron spin Hamiltonian. [1] Rosenthal et al., Phys. Rev. X 13, 031022 (2023) [2] Guo et al., arXiv:2307.11916v2 (2023)

Q 12.7 Mon 18:30 HS 3118

Coherent control of the Tin-Vacancy center with superconducting waveguides at mK temperatures — •Ioannis Karapatzakis[1], Jeremias Resch[1], Marcel Schrodin[1], Luis Kussi[1], Philipp Fuchs[2], Michael Kieschnick[3], Jan Meijer[3], Christoph Becher[2], David Hunger[1], and Wolfgang Wernsdorfer[1] — [1]Karlsruher Institut für Technologie, DE — [2]Universität des Saarlandes, DE — [3]Universität Leipzig, DE

Robust quantum networks require an interface between photons and long-lived spin degrees of freedom. Due to its strong spin-orbit splitting, the Tin-Vacancy center possesses long electron spin lifetimes around 1K. For high fidelity control, the use of microwave fields is required. However, the magnetic transitions are heavily suppressed in unstrained emitters. This limitation can be overcome by inducing strain and precisely aligning the DC magnetic field orientation. Recent work has shown the manipulation of the electron spin using aluminum wire bonds [1] and on-chip gold waveguides [2]. Both methods suffer from Ohmic losses in the microwave line, restricting coherence through heat induction. To overcome this challenge, we fabricate a superconducting coplanar waveguide made from Niobium on a diamond membrane through all-optical lithography. We induce strain in the diamond by using a polymer with a high coefficient of thermal expansion for fixation. We demonstrate coherent manipulation of the electron spin and evaluate the decoherence properties for different magnetic field orientations at mK temperature. [1] Rosenthal et al., Phys. Rev. X 13, 031022 (2023) [2] Guo et al., arXiv:2307.11916v2 (2023)

Q 12.8 Mon 18:45 HS 3118

Addressing single nuclear spins at telecommunication wavelength — Alexander Ulanowski[1], •Adrian Holzäpfel[2], Olivier Kuijpers[2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

Single emitters in solids are a particularly promising building block for large-scale quantum networks because their integration in micro- and nanodevices offers great potential for scalability. Previously, our group has demonstrated the coherent manipulation and efficient optical interfacing of individual erbium emitters in a micrometer-thin yttrium orthosilicate membrane by integrating it into a high finesse Fabry-Perot resonator [1]. In recent devices, we achieve a Purcell enhancement of their optical transition in the telecom C-band of up to 110. The coherence of our system could be greatly increased by encoding the information stored onto long-lived nuclear spins. We investigate two different approaches. First, we consider the superhyperfine interaction of a single erbium electron spin with the nuclear spin of neighboring yttrium ions. In a second approach, we study the 7/2 nuclear spin of the isotope Er167, opening a promising path to quantum repeater nodes with second-long coherence.

[1] A. Ulanowski, B. Merkel & A. Reiserer, Sci. Adv. 8, (2022).

Q 13: Quantum Technologies

Time: Monday 17:00–19:00 Location: HS 3219

Q 13.1 Mon 17:00 HS 3219

Alternative approach to quantum pulse gates — •Ankita Khanda, Laura Serino, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Integrated Quantum Optics, Institute for Photonic Quantum Systems, Paderborn Univerisity, Warburger Str. 100, 33098 Paderborn, Germany

Deep space communications and time-of-flight LiDAR applications can utilize ultrashort optical pulses for high bit rate and precision; however, successful implementation of such systems is challenging and requires single- or few-photon detection with very low mean photon numbers and high SNR. Noise rejection is critical in free-space, where background light is present or detected photon count is low. The most efficient method of noise elimination in the spectral-temporal domain is coherent time-frequency filtering. A quantum pulse gate (QPG) is a highly selective coherent temporal mode (TM) filter based on sum-frequency generation in a periodically-poled lithium niobate (PPLN) waveguide capable of single-photon level operation at telecom wavelengths without additional noise. In this work, we investigate noise effects of frequency up-conversion in target TM detection at telecom-only wavelengths in a PPLN QPG down to single-photon level. The pump and signal photon location in the telecom-range with small spectral separation allows for easy integration into the standard fiber-optic networks, but may give rise to additional noise channels. We will report progress on the project, including first results.

Q 13.2 Mon 17:15 HS 3219

Maiman's heritage, a thin disk cw singlemode Ruby laser for high precision metrology — •Walter Luhs[1], Thomas Müller-Wirts[2], Carsten Reinhardt[3], and Bernd Wellegehausen[4] — [1]Photonic Engineering Office, Herbert-Hellmann-Allee 57, 79189 Bad Krozingen, Germany — [2]TEM Messtechnik GmbH, Großer Hillen 38, 30559 Hannover, Germany — [3]Hochschule Bremen, Neustadtswall 30, 28199 Bremen, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Maiman's three-level 694 nm Ruby laser is well known as a pulsed laser but is considered to be difficult to operate as a cw system. This recently changed due to successful cw operation pumped with 405 nm diode lasers, Ref. [1] and further refs. therein. Here, we report on the first realization of a thin disk (microchip) cw Ruby laser of only 0.5 mm crystal thickness, allowing highly stable single-frequency operation without any further frequency selective element. Details of the system will be presented, and applications for high-precision metrology will be discussed.

[1] W. Luhs, B. Wellegehausen; Diode pumped compact single frequency cw ruby laser, J. Physics Communications 7 (2023) 0055007

Q 13.3 Mon 17:30 HS 3219

Hybrid Fiber-Solid State Laser with 3D-Printed Intracavity Lenses — •Simon Angstenberger, Pavel Ruchka, Mario Hentschel, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Stuttgart Research Center of Photonic Engineering, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Microscale 3D-printing has revolutionized micro-optical applications ranging from endoscopy, imaging, to quantum technologies. In all these applications miniaturization is key, and in combination with the nearly unlimited design space it is opening novel avenues. Here, we push the limits of miniaturization and durability by realizing the first fiber laser system with intra-cavity on-fiber 3D-printed optics. We demonstrate stable laser operation at over 20 mW output power at 1063.4 nm with a full width half maximum (FWHM) bandwidth of 0.11 nm and a maximum output power of 37 mW. Furthermore, we investigate the power stability and degradation of 3D-printed optics at Watt power levels. The intriguing possibilities afforded by free-form microscale 3D-printed optics allow us to combine gain in a solid-state crystal with fiber guidance in a hybrid laser concept. Therefore, our novel ansatz enables the compact integration of bulk active media in fiber platforms at substantial power levels.

Q 13.4 Mon 17:45 HS 3219

Ultra-low frequency noise diode-laser systems for quantum applications — •Niklas Kolodzie[1,2], Ivan Mirgorodskiy[1], Kai Dietze[2], Christian Nölleke[1], and Piet O. Schmidt[2,3] — [1]TOPTICA Photonics AG, Gräfelfing, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

Narrow-linewidth lasers are essential in many quantum applications which exploit ultra-cold atoms. Tasks like optical trapping or coherent qubit manipulation have high requirements on the laser frequency noise (FN). In many experiments it is crucial to keep FN at a minimum level: slow FN is responsible for the long-term stability, while fast FN ultimately limits the fidelity of qubit operations.

External-cavity diode lasers (ECDL) are the tool of choice for such applications due to their versatility and robustness: A wide range of atomic transitions in the visible and infrared frequency ranges can be addressed. However, ECDLs typically have a high level of FN due to relatively high cavity losses compared to other laser concepts.

We demonstrate an ultra-low noise laser (ULNL) by applying weak optical feedback from an additional external cavity to an ECDL. This method reduces fast FN i.e. reducing the Lorentzian part of the linewidth. We investigate the characteristics of the ULNL in detail: FN reduction with respect to different feedback power-levels, mode-stability and frequency stabilization to an optical reference. Finally, we integrate the ULNL into a calcium ion experiment and compare the performance to a state-of-the-art laser.

Q 13.5 Mon 18:00 HS 3219

Performance Comparison of Polarization Compensation Devices on a Deployed Inter City Fiber Link for Quantum Communication Applications — •Saili Naik[1,2], Gregor Sauer[1,2], Pritom Paul[1,2], and Fabian Steinlechner[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Str. 07, 07745 Jena, Germany — [2]Friedrich Schiller University, Institute of Applied Physics, Abbe Center of Photonics, Albert-Einstein-Str. 15, 07745 Jena, Germany

Within a quantum network, different properties of photons can be used to transmit quantum information. One such technique involves utilizing the polarization state of photons, due to ease of manipulation and detection. However, when such qubits are transmitted over long optical fiber links, their polarization state undergoes unpredictable changes caused by environmental factors. So, accurate measurement of quantum correlations in the polarization basis necessitates fast and precise compensation of these polarization drifts.

Several motorized polarization manipulation devices are available in the market, distinguished by distinct operating principles. In this work, we examine a range of performance parameters associated with these devices, including the response linearity, hysteresis, and operation speed. We also run compensation algorithms on these devices to assess their capacity for polarization compensation in low and high drift speed scenarios. This study aims to enhance our understanding of long-term behavior of polarization-based QKD systems in real-world application environments.

Q 13.6 Mon 18:15 HS 3219

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

The miniaturization of atom-based quantum sensor experiments towards robust and compact quantum sensor devices holds great potential to improve a variety of applications, such as timekeeping, navigation and high-sensitivity field sensing. Working on the physics packages, we develop and qualify necessary integration technologies to realize miniaturized, ultra-stable optical systems to generate, manipulate and detect atomic quantum gases. For further functionalization, active optical components are investigated. We report on our technology toolbox and the latest qualification efforts regarding the micro-integration of free-space optical systems using adhesive bonding processes.

Towards higher grades of system integration, one approach is to integrate optical subsystems within the ultra-high vacuum (UHV) system, requiring ultra-low outgassing properties of all bonds and components. Furthermore, additive manufacturing of ceramics and metals is utilized, e.g. to realize compact and functionalized vacuum systems.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers DLR50WM1949, 50RK1978, 50WM2070 and 50WM2268.

Q 13.7 Mon 18:30 HS 3219

Investigation of diffraction gratings and additively manufactured vacuum components for miniaturized atomic physics packages — •Alisa Ukhanova, Marc Christ, Conrad Zimmermann, Jörg Fricke, Olaf Brox, Robert Smol, Daniel Bandke, Jenichi Clairvaux Felizco, Andrea Knigge, and Markus Krutzik — Ferdinand-Braun-Institut (FBH), Leibniz-Institut für Höchstfrequenztechnik, Berlin

Atom-based quantum devices allow precise timekeeping and field sensing. The application of these sensors beyond the laboratory environment requires improvements of size, stability and user-friendliness. Here, we are developing a technology toolbox towards miniaturized cm-scale physics package. In this presentation we show results of the optical qualification of diffraction gratings for GMOTs with varying periods, duty cycles and coatings. Furthermore, 3D-printed ceramic and aluminum components for vacuum applications are investigated and a next generation compact physics package envisioned.

This work is supported by FBH and partially supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant number 50WM1949 and 50WM2070.

Q 13.8 Mon 18:45 HS 3219

Industrially fabricated ion trap chips for double-well coupling experiments — •Michael D.J. Pfeifer[1,2], Simon Schey[1,3], Matthias Dietl[1,2], Fabian Anmasser[1,2], Jakob Wahl[1,2], Marco Valentini[2], Martin van Mourik[2], Thomas Monz[2], Fabian Laurent[1], Clemens Rössler[1], Yves Colombe[1], and Philipp Schindler[2] — [1]Infineon Technologies Austria AG, Villach, Austria — [2]University of Innsbruck, Innsbruck, Austria — [3]Stockholm University, Stockholm, Sweden

We present surface ion trap chips, industrially fabricated at Infineon Technologies [1,2], that are capable of trapping ions in two separate rf potential wells. The chips are designed for investigating rf shuttling in the large separation and in the coupling regimes as element of a scalable architecture [1]. The design parameters of a surface ion trap in the rf coupling regime with optimal ion height and ion-ion distance are investigated.

The ion traps are fabricated on the dielectric substrates Fused Silica and Sapphire. The status of the microfabrication on these materials is discussed, with a focus on optical and electric properties, as well as on wafer bow.

[1] Ph. Holz, S. Auchter et al., Adv. Quantum Technol. 3, 2000031 (2020)

[2] S. Auchter, C. Axline et al., Quantum Sci. Technol. 7, 035015 (2022)

Q 14: Precision Spectroscopy of Atoms and Ions I (joint session A/Q)

Time: Tuesday 11:00–13:00 Location: HS 1098

Q 14.1 Tue 11:00 HS 1098

Implementing a Josephson Voltage Standard on a Penning Trap for the Nuclear Magnetic Moment Measurements of ^{2}D, ^{3}He and ^{7}Li — •Annabelle Kaiser[1], Stefan Dickopf[1], Marius Müller[1], Ralf Behr[2], Ute Beutel[1], Ankush Kaushik[1], Luis Palafox[2], Stefan Ulmer[3,4], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch Technische Bundesanstalt, Braunschweig, Germany — [3]RIKEN, Wako, Japan — [4]HHU Düsseldorf, Germany

Penning traps are versatile tools for high-precision measurements of e.g. the hyperfine structure from which atomic masses, binding energies and electron as well as nuclear magnetic moments can be extracted. For the latter, a spin-flip needs to be resolved with a change in signal that is barely detectable before the background noise, using methods described in [1]. This requires an ultra-stable trapping environment and extremely cold ion temperatures. A new technique will be presented, which reduces the noise originating from the voltage sources generating the electrostatic trapping potential: By implementing a tunable 10 V Josephson voltage standard, the stability of the ion's axial frequency was measured to be twice as stable (10 ppb over 8 minutes, at 800 kHz absolute frequency) as with the typical low-noise voltage sources UM1-14. An environment this stable enables the direct high-precision measurements of the nuclear magnetic moment of ^{2}D, ^{3}He and ^{7}Li. First results of the frequency stability improvement will be presented, along with the status of the project.

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

Q 14.2 Tue 11:15 HS 1098

Measurement of the bound-electron *g*-factor in ^{4}He$^+$ for the determination of the electron mass — •Marius Müller[1], Stefan Dickopf[1], Annabelle Kaiser[1], Ute Beutel[1], Ankush Kaushik[1], Stefan Ulmer[2,3], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland — [2]RIKEN, Wako, Japan — [3]Heinrich-Heine-Universität, Düsseldorf, Deutschland

The determination of fundamental constants is of great importance for many fields of science and technology. One of these fundamental constants is the atomic mass of the electron, which was previously determined to a fractional uncertainty of 30 ppt by a collaborative effort of high-precision Penning-trap *g*-factor measurements of hydrogen-like carbon-12 and state-of-the-art bound-state QED calculations [1]. Recent measurements of the helium-4 mass at LIONTRAP with a relative precision of 12 ppt [2] allow for an independent cross-check of the electron mass in a different ionic system and further enable an improvement in precision by a factor of 2.5.

At our experimental Penning-trap setup at the MPIK in Heidelberg [3], we are currently conducting high-precision bound-electron *g*-factor measurements of ^{4}He$^+$ in order to improve the precision of the atomic mass of the electron. The current status and first experimental results of the helium-4 measurement campaign will be presented.

[1] S. Sturm *et al.*, Nature 506, 467 (2014)

[2] S. Sasidharan *et al.*, Phys. Rev. Lett. 131, 093201 (2023)

[3] A. Schneider *et al.*, Nature 606, 878 (2022)

Q 14.3 Tue 11:30 HS 1098

Precision ground-state hyperfine and Zeeman spectroscopy on ^{9}Be ions — •Stefan Dickopf[1], Bastian Sikora[1], Annabelle Kaiser[1], Marius Müller[1], Stefan Ulmer[2], Vladimir Yerokhin[1], Zoltan Harman[1], Christoph Keitel[1], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Institut für Experimentalphysik, Heinrich-Heine-Universität, Düsseldorf, Germany

Measurements of the Zeeman splitting in systems with nuclear magnetic moments can be used to infer the shielded nuclear and the bound electron *g*-factors, as well as the zero-field hyperfine splitting [1]. We measured the Zeeman splitting of ^{9}Be^{3+} and compare it to measurements on ^{9}Be^{1+} [2] to test the theory of the diamagnetic shielding factor [3] on the parts per billion level. Additionally, we compare our measured zero-field splitting with the value obtained in ^{9}Be^{1+} via the so-called hyperfine specific difference to cancel theoretically intractable nuclear structure contributions. Recent progress and the latest results will be presented.

[1] A. Schneider et al, Nature 606, 878-883 (2022)

[2] D. J. Wineland, J. J. Bollinger, and Wayne M. Itano, Phys. Rev. Lett. 50, 628-631 (1983)

[3] K. Pachucki and M. Puchalski, Optics Communication 283, 641-643 (2010)

Q 14.4 Tue 11:45 HS 1098

Isotope shift spectroscopy in ultracold atomic mercury — •Thorsten Groh, Sascha Heider, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

Low energy beyond standard model theories predict a new boson, that would act as a new force carrier coupling neutrons and leptons via a Yukawa like interaction [Delaunay, PRD 96, 093001; Berengut, PRL 120, 091801]. Precision spectroscopy of atomic isotope shifts could resolve this coupling as an energy shift of electronic levels. New physics signatures would emerge as nonlinearities in King plots of scaled isotope shifts on different electronic transitions.

We cool mercury in a magneto-optical trap. Our results on high resolution deep UV laser spectroscopy show strong deviations from linearity. Our multidimensional King plot analysis indicates that these are dominated by standard model contributions, quadratic field shifts and nuclear deformations. With recent improvements on the machine and spectroscopy results on additional lines we investigate the nonlinearity origins further.

Q 14.5 Tue 12:00 HS 1098

Spectroscopy of calcium on an atomic vapor — •Lukas Möller, David Röser, Frederik Wenger, Andreas Reuss, Anica Hamer, and Simon Stellmer — Physikalisches Institut, Universität Bonn

Calcium is an element that posseses multiple desireable qualities that make it suitable for a multitude of applications, including atomic clocks and the search for beyond standard model physics. All of these applications are based on high precision spectroscopy. Spectroscopy on thermal atomic vapor is a straightforward and well-estabished method. By applying a lock-in detection scheme that uses both frequency and amplitude modulation to saturated absorption spectroscopy, we measure the isotope shifts of the 423-nm 1S0 -> 1P1 transition for all stable calcium isotopes.

Q 14.6 Tue 12:15 HS 1098

Developments towards quantum logic spectroscopy for high-precision CPT symmetry tests in a cryogenic Penning trap

— •Jan Schaper[1], Julia Coenders[1], Moritz von Boehn[1], Nima Hashemi[1], Juan Manuel Cornejo[1], Stefan Ulmer[3,4], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Ulmer Fundamental Symmetries Laboratory, Riken, Japan — [4]Heinrich-Heine-Universität Düsseldorf, Germany

High-precision matter-antimatter comparisons allow to test CPT symmetry and to search for new physics beyond the standard model. The BASE collaboration contributes to these tests by measuring the charge-to-mass ratio and g-factor of protons and antiprotons in cryogenic Penning traps [1-3]. The BASE experiment at the Leibniz University Hannover is developing measurement schemes based on sympathetic cooling and quantum logic spectroscopy to further increase sampling rates, using $^9Be^+$ both as cooling and logic ion [4].

This talk will present recent advances, including adiabatic transport in the ms-regime [5] and ground-state cooling of a single $^9Be^+$ ion [6]. Furthermore, upcoming changes to the experimental apparatus, including a redesigned Penning trap stack, will be shown.

[1] G. Schneider et al., Science 358, 1081 (2017) [2] C. Smorra et al., Nature 550, 371 (2017) [3] M.J. Borchert et al., Nature 601, 53 (2022) [4] Juan M Cornejo et al 2021 New J. Phys. 23 073045 [5] Meiners et al., arXiv:2309.06776 (2023) [6] Cornejo et at., arXiv:2310.18262 (2023)

Q 14.7 Tue 12:30 HS 1098

X-Ray Spectroscopy of the Kα transitions in He-like Uranium — •Philip Pfäfflein[1,2,3], Steffen Allgeier[4], Sonja Bernitt[1,2,3], Andreas Fleischmann[4], Marvin Friedrich[4], Alexandre Gumberidze[2], Christoph Hahn[1,2], Daniel Hengstler[4], Marc O. Herdrich[1,2,3], Felix Kröger[1,2,3], Patricia Kuntz[4], Michael Lestinsky[2], Bastian Löher[2], Esther B. Menz[1,2,3], Uwe Spillmann[2], Sergiy Trotsenko[1,2], Günter Weber[1,2], Binghui Zhu[1,2,3], Christian Enss[4], and Thomas Stöhlker[1,2,3] — [1]HI Jena, Germany — [2]GSI, Darmstadt, Germany — [3]Jena University, Germany — [4]Heidelberg University, Germany

Helium-like ions are the simplest atomic multi-body systems. Their study along the isoelectronic sequence allows for precision tests of the interplay of the effects of electron–electron correlation, relativity and quantum electrodynamics (QED) within a wide range of electromagnetic field strengths. Heavy highly charged ions are ideal for probing higher order QED terms. For the 1s state in uranium, e.g. their contributions are on the 1 eV level at binding energies of above 100 keV.

In spring 2021 an X-ray spectroscopy study of helium-like uranium ions has been performed at the electron cooler of the low-energy storage ring CRYRING@ESR at GSI, Darmstadt using metallic magnetic calorimeter detectors. The achieved spectral resolution reveals the substructure of the Kα_1 and Kα_2 lines for the first time. Using two detectors the Doppler shift was deduced from the recorded spectra. This breakthrough in X-ray spectroscopy enables future precision tests of bound-state QED and many-body effects in extreme field strengths.

Q 14.8 Tue 12:45 HS 1098

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

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 single molecular ion, one well-controllable atomic ion is co-trapped, coupling strongly to the molecule via the Coulomb interaction. The shared motional state is used as a bus to transfer information about the internal state of the molecular ion to the atomic ion. Using calcium as a logic ion, we have implemented a quantum logic scheme to detect population transfer on a co-trapped spectroscopy ion. The interaction is driven by a far detuned Raman laser setup. We present the latest progress of our experiment, aiming at high precision spectroscopy of molecular and complex atomic ions.

Q 15: Optomechanics

Time: Tuesday 11:00–13:00 Location: HS 1015

Invited Talk Q 15.1 Tue 11:00 HS 1015

Levitated nanoparticles as testbeds for fundamental aspects of physics — •Julen S. Pedernales — University of Ulm, Ulm, Germany

Quantum mechanics has been enormously successful at describing the microscopic world, however, at scales that exceed the mass of a few thousand atoms, it remains largely unexplored. Recent progress in the quantum control of the mechanical degrees of freedom of solids suspended in a vacuum suggests that this situation might be changing in the near to mid-term future. Containing billions of atoms, levitated nanoparticles might be able to perform quantum experiments in an unprecedented mass regime, and thus, interrogate Nature about fundamental aspects of physics for which we do not have an answer: does the linearity of quantum mechanics hold at macroscopic scales? or, how does the gravitational field of a source in superposition look like?

In my talk, I will examine the opportunities and challenges that this nascent quantum platform presents to address these fascinating questions. First, I will present a collection of proposed techniques to extend the coherence times and shorten the duration of experiments aimed at realizing matter-wave interferometry with levitated solids. Secondly, I will discuss the prospects of observing gravitationally mediated entanglement between levitated solids–a route to explore the quantumness of gravity. Finally, I will introduce an alternative strategy for the detection of the quantumness of gravity which does not rely on the generation of entanglement.

Q 15.2 Tue 11:30 HS 1015

Levitated optomechanics in microgravity — •Govindarajan Prakash[1], Sven Herrmann[1], Claus Lämmerzahl[1], and Christian Vogt[2] — [1]ZARM (Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation), Universität Bremen — [2]BIAS (Bremer Institut für angewandte Strahltechnik GmbH)

Optomechanical levitation of nanoparticles provides a promising platform to perform tests with macroscopic particles on the interface between quantum and classical regimes. Schemes of such tests involve optical trapping, feedback cooling, and release and retrapping of nanoparticles. Here, we present how this allows us to perform force sensing of the order of attonewtons in microgravity conditions at the drop towers of ZARM in Bremen using silica nanoparticles. We present our progress thus far where we discuss first results from microgravity and hypergravity conditions.

Q 15.3 Tue 11:45 HS 1015

The First Levitated Optomechanics Experiment in Space — Jack Homans[1], Govindarajan Prakash[2], Chris Bridges[3], Peter Nisbet-Jones[4], Elliot Simcox[1], Simeon Modre[1], Tiberius Georgescu[1], •Christian Vogt[2,5], and Hendrik Ulbricht[1] — [1]School of Physics and Astronomy, University of Southampton, Southampton SO17 1BJ, UK — [2]ZARM, Center of Applied Space Technology and Microgravity, Uni Bremen — [3]Surrey Space Centre, OBDH Group, University of Surrey, Guildford, U.K. — [4]Twin Paradox Labs, London, U.K. — [5]BIAS, Institute of Applied Beam Technology, Bremen, Germany

Optically levitated nanospheres hold great promises for investigations of quantum behavior of large masses. In order to observe these, the particles must be isolated from sources of decoherence e.g. collisions with gas molecules or photons. The latter can hardly be suppressed in optical traps. One way to circumvent this problem is to switch off the trap and allow for a free evolution of the particles' wave packet as it can be done in space. A first demonstrator for this technology will be launched by the end of 2024 with the reentry capsule Nyx, by the company TEC. This talk we will focus on our payload design, the given boundary conditions and our mission goals.

Q 15.4 Tue 12:00 HS 1015

Testing Spontaneous Collapse Models with Levitated Naphthalene — •Marit O. E. Steiner, Julen S. Pedernales, and Martin B. Plenio — Institute of Theoretical Physics, Ulm University

Spontaneous collapse models aim to address the quantum-to-classical transition and the measurement problem through non-linear, stochastic modifications of the Schrödinger equation. A promising route to test the existence of these modifications is through matter-wave interference experiments of increasing mass and coherence length. In particular, the nascent field of levitated optomechanics, promises the ability to perform matter-wave interference at unprecedented scales.

In my presentation, I will advocate for an unconventional material in levitated optomechanics: pentacene-doped naphthalene. Leveraging photo-excited triplet states in pentacene, it is possible to achieve remarkable nuclear spin hyperpolarization, up to 80% polarization rates with relaxation times of T1=800 hours. These properties make it an ideal candidate for matter-wave interferometry. Stronger spin-dependent forces allow shorter interference times, reducing susceptibility to various noise sources. Additionally, the homogeneous spin distribution mitigates unwanted rotations in nanoparticles, an expected challenge in experiments with fewer spins.

I will introduce a novel experimental protocol leveraging these properties, as well as discuss the intricacies of the protocol and showcase its ability to impose bounds on the free parameters of the Continuous Spontaneous Localization model compared to existing methodologies.

Q 15.5 Tue 12:15 HS 1015

Classical phase-space model for gravity-mediated entanglement — •Marta Maria Marchese, Martin Plávala, Matthias Kleinmann, and Stefan Nimmrichter — Universität Siegen, Siegen, Germany

Whether gravity is fundamentally quantum or not is still a debated question. On one side, there are several well-established quantum-gravity theories, on the other, there are semi-classical descriptions that treat the gravity field as a classical measurement-feedback channel. The lack of experimental evidence leaves the problem still unresolved, but experiments with massive levitated particles have been proposed: witnessing entanglement generated by the gravitational interaction between two masses in a matter-wave interferometer is claimed to probe the quantum nature of the gravitational field. Here, we argue that such a scheme is not sufficient to rule out all possible classical descriptions of gravity. Indeed, one can achieve the same entanglement built up through a classical evolution of the Wigner function of the two gravitationally interacting masses, making use of a second-order approximation of the Newtonian potential. This suggests that alternative experimental schemes be developed to test the quantum nature of gravity.

Q 15.6 Tue 12:30 HS 1015

Dynamics of diamagnetically levitated superconducting ellipsoids — •Fynn Köller[1], Klaus Hornberger[1], and Benjamin A. Stickler[2] — [1]University of Duisburg-Essen, Faculty of Physics, Lotharstraße 1, 47058 Duisburg, Germany — [2]Ulm University, Institute for Complex Quantum Systems, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Superconducting bodies can be diamagnetically levitated in magnetic quadrupole traps, where their dynamics are governed by the internal magnetization induced by the trapping field. We derive an analytical expression for the magnetization in ellipsoids, which is fully characterized by the induced dipole and quadrupole moments. These moments give rise to diamagnetic forces and torques as well as spin-rotation coupling due to the Einstein-de Haas and Barnett effects, enabling full three-dimensional alignment in the trap centre. We study the resulting dynamics and show that signatures of strong spin-rotational coupling will become observable in upcoming experiments with levitated micron-sized superconductors.

Q 15.7 Tue 12:45 HS 1015

Decoherence of dielectric rotors by thermal emission — •Jonas Schäfer[1], Benjamin A. Stickler[2], and Klaus Hornberger[1] — [1]Faculty of Physics, University of Duisburg-Essen — [2]Institute for Complex Quantum Systems, Ulm University

Levitated nanoparticles can be used for sensing applications and fundamental tests of quantum theory [1,2]. The center-of-mass motion has already been driven into the quantum ground state [1], while the full rotation dynamics are expected to enter the quantum regime soon [2,3,4,5]. This talk presents the master equation quantifying the impact of thermal emission on the ro-translational quantum state of an arbitrarily sized dielectric rigid rotor. It involves only the bulk permittivity, geometry, and temperature of the particle, and it accounts for internal photon scattering to all orders. We find the orientation state to decohere even for spheres in the point-particle limit, which can be understood a consequence of the vector character of the thermally driven polarization currents.

[1] Gonzalez-Ballestero, Aspelmeyer, Novotny, Quidant, and Romero-Isart, Science 374, eabg3027 (2021)

[2] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589-597 (2021)

[3] Schäfer, Rudolph, Hornberger, and Stickler, PRL 126, 163603 (2021)

[4] Pontin, Fu, Toroš, Monteiro, and Barker, Nat. Phys. 19, 1003-1008 (2023)

[5] Kamba, Shimizu, and Aikawa, arXiv:2303.02831 (2023)

Q 16: Bosonic Quantum Gases III (joint session Q/A)

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

Q 16.1 Tue 11:00 Aula

Sub-unity superfluid fraction of a supersolid from self-induced Josephson effect — •Nicolò Antolini[1,2], Giulio Biagioni[2,3], Beatrice Donelli[1,2,4,5], Luca Pezzè[1,2,4], Augusto Smerzi[1,2,4], Marco Fattori[1,2,3], Andrea Fioretti[2], Carlo Gabbanini[2], Massimo Inguscio[1,6], Luca Tanzi[1,2], and Giovanni Modugno[1,2,3] — [1]LENS, University of Florence — [2]CNR-INO — [3]Department of Physics and Astronomy, University of Florence — [4]QSTAR — [5]Università degli Studi di Napoli — [6]Università Campus Bio-Medico di Roma

Many quantum materials in various systems feature a spatially modulated macroscopic wavefunction resulting from spontaneous breaking of gauge and translational symmetries. Their connection with supersolids has only been traced in a few cases since a universal property able to quantify the differences between supersolids, superfluids/superconductors, and crystals has not been established. A key property is the superfluid fraction, measuring the reduction in superfluid stiffness due to spatial modulations, leading to the non-standard superfluid dynamics of supersolids. We employ the Josephson effect to locally measure the superfluid fraction in a supersolid. Even without a physical barrier, the Josephson effect arises spontaneously in a supersolid, and single lattice cells act as self-induced Josephson junctions. We studied a cold-atom dipolar supersolid, revealing a significant sub-unity superfluid fraction. Our results point to new research directions, like the study of partially quantized vortices and supercurrents, and have an impact on the understanding of other supersolid-like systems.

Q 16.2 Tue 11:15 Aula

Supersolidity in a driven quantum gas — •Nikolas Liebster[1], Marius Sparn[1], Elinor Kath[1], Keisuke Fujii[2], Sarah Görlitz[2], Tilman Enss[2], Helmut Strobel[1], and Markus Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 19, 69120 Heidelberg, Germany

Driven systems are of fundamental scientific interest, as they can display properties that are radically different from similar systems at equilibrium. However, systems out of equilibrium are difficult to describe theoretically, as they are inherently time-dependent and deeply nonlinear. This makes the study of such systems an ideal task for quantum field simulators, in which complex dynamics emerge naturally and can be probed experimentally. Here, we demonstrate the emergence of supersolidity in a driven, two-dimensional superfluid, that only has contact interactions. The self-stabilized system is characterized by simultaneously broken translational and U(1) gauge symmetry, and emerges as a result of large occupations of phononic modes due to driving. We characterize the state by observing collective modes of the lattice as well as lattice phonon propagation. We also show that the system maintains phase rigidity, a key property of superfluidity. This work introduces a novel type of supersolid that is readily experimentally accessible, and establishes a conceptual framework for describing elementary excitations of driven systems.

Q 16.3 Tue 11:30 Aula

Strong-coupling expansion for disordered Bose-Hubbard model — •Renan da Silva Souza[1], Axel Pelster[2], and Francisco Ednilson Alves dos Santos[3] — [1]Goethe-Universität, Institut für Theoretische Physik, Frankfurt am Main, Germany — [2]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [3]Departamento de Física, Universidade Federal de São Carlos, Brazil

We identified the different ground states corresponding to the disordered Bose-Hubbard model at zero and finite temperatures and for small tunneling energies. Employing a field-theoretical approach, we constructed a strong-coupling expansion. By utilizing the Poincaré-Lindstedt method, we calculated a renormalized expression for the local density of states, providing clear differentiation between the Mott-insulator and Bose-glass phases. Applying a resummation technique, we computed the expression for the disorder ensemble average of the spectral function. Its analysis shows that disorder leads to an increase in the effective mass of both quasi-particle and -hole excitations of the Mott phase. And it yields the emergence of damped states, which exponentially decay during propagation in space and dominate the whole band when disorder becomes comparable to interactions. We argue that such damped-localized states correspond to single-particle excitations of the Bose-glass phase. Our results for the phase boundary compare well against stochastic and local mean-field numerical predictions.

[1] New J. Phys. **23**, 083007 (2021) and **25**, 063015 (2023)

Q 16.4 Tue 11:45 Aula

Dynamical analysis of the chaotic phase in the Bose-Hubbard model — Óscar Dueñas Sánchez[1] and •Alberto Rodríguez[1,2] — [1]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain — [2]Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, E-37008 Salamanca, Spain

We study the dynamical manifestation of the Bose-Hubbard model's chaotic phase [1] by analysing the temporal behaviour of connected two-point density correlations on experimentally accessible time scales up to a few hundred tunneling times. The exact time evolution of initial states with unit density reveals that the chaotic phase can be unambiguously identified from the 'early' time fluctuations of the considered observable around its equilibrium value [2]. The emergence of the chaotic phase is also seen to leave an imprint in the initial growth of the time signals. Specifically, the short time evolution in systems with $L \gtrsim 40$ is scrutinized to investigate the potentially diffusive spreading of density correlations within the chaotic phase.

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

Q 16.5 Tue 12:00 Aula

Emergence of fluctuating hydrodynamics in chaotic quantum systems — •Julian Wienand[1,2,3], Simon Karch[1,2,3], Alexander Impertro[1,2,3], Christian Schweizer[1,2,3], Ewan McCulloch[4], Romain Vasseur[4], Sarang Gopalakrishnan[5], Monika Aidelsburger[1,2,3], and Immanuel Bloch[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [4]Department of Physics, University of Massachusetts, Amherst, MA 01003, USA — [5]Department of Electrical and Computer Engineering, Princeton University, Princeton, NJ 08544, USA

A fundamental principle of chaotic quantum dynamics is that local subsystems eventually approach a thermal equilibrium state. Large subsystems thermalise slower: their approach to equilibrium is limited by the hydrodynamic build-up of fluctuations on extended length scales. We perform large-scale quantum simulations that monitor particle-number fluctuations in tunable ladders of hard-core bosons and explore how the build-up of fluctuations changes as the system crosses over from ballistic to chaotic dynamics. Our results indicate that the growth of large-scale fluctuations in chaotic far-from-equilibrium systems is even quantitatively determined by equilibrium transport coefficients, in agreement with the predictions of fluctuating hydrodynamics. This emergent hydrodynamic behaviour of fluctuations provides a novel test of fluctuation-dissipation relations far from equilibrium.

Q 16.6 Tue 12:15 Aula

Extreme wave events and spacetime defects in a spinor Bose-Einstein condensate — •Yannick Deller, Ido Siovitz, Alexander Schmutz, Felix Klein, Helmut Strobel, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Ruprecht-Karls Universität Heidelberg, Deutschland

Many-body systems far from equilibrium can exhibit self-similar dynamics characterized by universal exponents. Numerical studies of a quenched ferromagnetic spinor BEC have revealed the appearance of extreme wave events on the way to the universal regime [1]. Furthermore, as a result of these caustics, real-time instanton defects are generated, which take on the form of space-time vortices in the transversal spin order parameter. However, the random appearance of real-time instantons in space and time makes it experimentally challenging to study these excitations in a controlled way. Thus we aim for deterministic preparation of a single instanton event. We employ local spin-dependent phase imprints, which lead to excitations in the transversal spin length. We probe their time evolution and characterize their structure with spatially resolved detection of all relevant spin observables.

[1] Siovitz et. al. , PRL 131, 183402 (2023)

Q 16.7 Tue 12:30 Aula

Entrainment of a continuous time crystal — Anton Bölian[1], •Phatthamon Kongkhambut[1], Jim Skulte[1], Ludwig Mathey[1], Jayson G. Cosme[3], Hans Kessler[2], and Andreas Hemmerich[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Quantenphysik, Universität Hamburg, Germany. — [2]Physikalisches Institut der Universität Bonn, Germany. — [3]National Institute of Physics, University of the Philippines, Diliman, Quezon City, Philippines.

Discrete and continuous time crystals are novel dynamical many-body states, that are characterized by robust self-sustained oscillations, emerging via spontaneous breaking of discrete or continuous time translation symmetry. Here, we demonstrate dynamical control of a continuous time crystal by driving it into a discrete time crystalline state. This transition is related to subharmonic entrainment of classical limit cycles, which arises here on the level of many-body quantum systems. Specifically, we prepare a continuous time crystal in a pumped atom-cavity system oscillating at a frequency ω_{CTC} and subsequently modulate the continuous pump intensity with a frequency ω_{dr} close to $2\,\omega_{\mathrm{CTC}}$. For sufficiently large modulation strengths, the emission frequency switches from ω_{CTC} to $\omega_{\mathrm{CTC}} = \omega_{\mathrm{dr}}/2$, which demonstrates the phase transition to a discrete time crystal.

Q 16.8 Tue 12:45 Aula

Effects of quantum depletion and gradient corrections on the critical atom number of dipolar droplets — Milan Radonjić[1,2], Axel Pelster[3], and •Antun Balaž[2] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

The first experimental realization of quantum droplets in dipolar condensates [1] has highlighted the importance of quantum fluctuations [2], which were later shown to be the main source of system's stability against the dipolar collapse. The droplets were predicted and shown to be self-bound beyond the critical atom number even without the trap. However, there is a systematic difference in theoretical estimates of the critical atom number and experimental results [3]. Here we use an approach based on the extended Gross-Pitaevskii equation, which includes quantum depletion and beyond-LDA gradient corrections, to numerically and variationally study their effects on the critical atom number.

[1] H. Kadau et al., Nature **530**, 194 (2016).

[2] A. R. P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011); Phys. Rev. A **86**, 063609 (2012).

[3] F. Böttcher et al., Phys. Rev. Research **1**, 033088 (2019).

Q 17: Quantum Information I

Time: Tuesday 11:00–13:00 Location: HS 1199

Q 17.1 Tue 11:00 HS 1199

Deciding Observability in Quantum Dynamics Made Easy — •Thomas Schulte-Herbrüggen and Markus Wiener — Technical University of Munich (TUM)

In quantum engineering a fundamental question arises: given a controlled quantum dynamical system, for which observables can measurements give full information for system identification?

In finite-dimensional closed systems, a unified (Lie) frame of quantum systems theory settles this observability problem—as will be illustrated in paradigmatic n-qubit systems. Implications and generalisations will be outlined as well.

Q 17.2 Tue 11:15 HS 1199

Towards exact factorization of quantum dynamics via Lie algebras — •David Edward Bruschi[1], André Xuereb[2], and Robert Zeier[3] — [1]Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, Jülich, Germany — [2]Department of Physics, University of Malta, Malta — [3]Quantum Control (PGI-8), Forschungszentrum Jülich, Jülich, Germany

Determining exactly the dynamics of a physical system is the paramount goal of any branch of physics. Quantum dynamics are characterized by the non-commutativity of operators, which implies that the dynamics usually cannot be tackled analytically and requirecad-hoc solutions or numerical approaches. A priori knowledge on the ability to obtain exact results would be of great advantage for many tasks of modern interest, such as quantum computing, quantum simulation and quantum annealing.

In this work we lay the foundations for an approach to determine the dimensionality of a Hamiltonian Lie algebra by appropriately characterizing its generating terms. This requires us to develop a new tool to construct sequences of operators that determine the final dimension of the algebra itself. Our work is exact and fully general, therefore providing statements on the ultimate ability to exactly control the dynamics or simulate specific classes of physical systems. This work has important implications not only for theoretical physics, but it also aids our understanding of the structure of the Hilbert space, as well as Lie algebras.

Q 17.3 Tue 11:30 HS 1199

Analytical quantum dynamics of coupled harmonic oscillators — •David Edward Bruschi — Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, Jülich, Germany

Harmonic oscillators are paramount systems in quantum physics. They are used to model a variety of physical systems, among which the modes of the electromagnetic field are a preeminent example. Dynamics of coupled quantum harmonic oscillators have been studied extensively, however, simple exact analytical solutions to problems of key interest have so far been lacking.

We employ symplectic geometry and the covariance matrix formalism in the context of quantum dynamics of coupled harmonic oscillators to provide the analytical solution to a few problems of interest: the validity of the rotating wave approximation for bosonic systems; exact solutions to (multimode and multi-oscillator) quantum optomechanical systems; dynamics of two coupled harmonic oscillators with single and two-mode squeezing. We conclude by commenting on current research and future direction.

Q 17.4 Tue 11:45 HS 1199

Indistinguishability of identical bosons from a quantum information theory perspective — Matthias Englbrecht[1,2], Tristan Kraft[1,2], Christoph Dittel[3,4,5], Andreas Buchleitner[3,4], •Géza Giedke[6,7], and Barbara Kraus[1,2] — [1]Institute for Theoretical Physics, University of Innsbruck, Innsbruck, Austria — [2]Department of Physics, QAA, TU Munich, Garching, Germany — [3]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [4]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [5]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [6]Donostia International Physics Center, San Sebastián, Spain — [7]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

We present a general theory of indistinguishability of identical bosons in experiments consisting of passive linear optics followed by particle number detection. Our approach uses tools from quantum information theory and the results do neither rely on additional assumptions on the input state of the interferometer, such as fixed mode occupation number, nor on the degrees of freedom that potentially make the particles distinguishable. We identify the expectation value of the projector onto the N-particle symmetric subspace as an operationally meaningful measure of indistinguishability, and derive tight and efficiently measureable lower bounds. We present a definition of perfect distinguishability and characterize the corresponding set of states.

Q 17.5 Tue 12:00 HS 1199

Fourier analysis of many-body transition amplitudes and states — •Gabriel Dufour and Andreas Buchleitner — Physikalisches Institut der Albert-Ludwigs-Universität Freiburg

The Fourier transform over a finite group is a generalisation of the ordinary discrete Fourier transform which allows the analysis of a function's behaviour under non-abelian transformations of its domain. We apply the Fourier transform over the symmetric group S_N to the set of multiparticle transition amplitudes arising from the permutations of N identical particles. For indistinguishable particles, these amplitudes add up coherently, giving rise to many-particle interference. The Fourier transform provides an analysis of the counting statistics at the output of multiparticle and multimode interferometers in terms of contributions from irreducible symmetry types. We apply this formalism to the interference of partially distinguishable bosons or fermions, whose states can likewise be submitted to a Fourier analysis, and to the determination of suppressed transitions for states of a given symmetry type.

Q 17.6 Tue 12:15 HS 1199

Correlations in two-particle quantum tunneling — •Jonathan Brugger, Christoph Dittel, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany

Quantum tunneling is key for our understanding of diverse processes in nature, such as nuclear and chemical reactions. While the tunneling of a single particle is nearly perfectly understood, we still lack a comprehensive understanding of the tunneling processes of two or more interacting particles: Under which conditions do they tunnel individually or in a correlated way? What is the role and influence of the particles' interaction? And is there an underlying spectral structure?

Here we answer these questions for the tunneling dynamics of two interacting bosons via exact numerical diagonalization, for hard-core and soft-core Coulomb, as well as contact interaction of variable strength. We find that correlated two-particle tunneling is the primary process, while uncorrelated single-particle tunneling is due to resonances between the two-particle system's eigenfunctions. We determine the necessary prerequisites for the latter and provide an intuitive picture of the underlying spectral structure. As a corollary, we establish a diagnostic protocol to infer the particles' interaction mechanism from interaction-induced dynamical signatures, via an experimentally readily accessible observable.

Q 17.7 Tue 12:30 HS 1199

Generalization of the Peres test: Multi-slit and multi-particle extension — •Ece Ipek Saruhan[1,2], Marc-Oliver Pleinert[2], and Joachim von Zanthier[2] — [1]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Boltzmanngasse 3, A-1090 Vienna, Austria — [2]Quantum Optics and Quantum Information Group, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany

The axioms of quantum mechanics provide limited information regarding the structure of the Hilbert space, such as the underlying number system, which may be real, complex, or hyper-complex. Asher Peres proposed a method to test hyper-complex quantum mechanics with a single particle and three scatterers [1]. In this talk, we introduce a convenient way to derive the test and extend it to a higher number of particles and scatterers (slits). We show that the sensitivity to detect - still hypothetical - hyper-complex phases changes with the number of slits and particles. In particular, we find that if one wants to test d vs. k dimensional theories where $d < k$, one must use $d + 1 \leq s \leq k$ slits. [1] A. Peres, Phys. Rev. Lett. 42, 683 (1979)

Q 17.8 Tue 12:45 HS 1199

Demonstration of entanglement-enabled work extraction — •Alexander Stahl[1], Michael Kewming[2], John Goold[2], Daniel Pijn[1], Ulrich Poschinger[1], and Ferdinand Schmidt-Kaler[1] — [1]Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Department of Physics, Trinity College Dublin, Dublin 2, Ireland

Trapped ion quantum computers provide an ideal platform for experimental studies in the field of quantum thermodynamics. We experimentally realize a work extraction protocol, converting entanglement into classical correlation and then into work. In this protocol, a 'demon' has access to an entangled ressource state shared with an 'agent'. The agent has only local access, such that this ressource appears to be thermal. By a sequence of manipulations, the demon can betray the agent and use information gained about the agents state to extract work. We show how this corroborates the work extraction protocol proposed in [1] and that the maximum work extraction is indeed bound by the concurrence as $\frac{\delta W}{E} \gtrsim \frac{C^2}{2}$. To enable the implementation of the protocol, the measurement outcome of qubits has to be used for a classical decision logic, such that a coherent feedforward for the following operations can be realized. Specifically, in the shuttling based trapped ion quantum computer this requires the capability to decide on a μs-timescale about future ion transports and laser pulses to execute.

[1] G. Francica, J. Goold, F. Plastina, and M. Paternostro, npj Quantum Information 3 (2017)

Q 18: Trapping and Cooling of Atoms (joint session Q/A)

Time: Tuesday 11:00–13:00 Location: HS 1221

Invited Talk Q 18.1 Tue 11:00 HS 1221

Continuous lasing and pinning of the dressed cavity resonance with strongly-coupled ^{88}Sr atoms in a ring cavity — •Vera Schäfer — JILA, University of Colorado, Boulder, USA — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

Superradiant lasers are a promising path for realising a narrow-linewidth, high-bandwidth active frequency reference. They shift the phase memory from the optical cavity, which is subject to technical and thermal vibration noise, to an ultra-narrow optical atomic transition of an ensemble of cold atoms trapped inside the cavity. Our previous demonstration of pulsed superradiance on the mHz transition in ^{87}Sr achieved a fractional Allan deviation of $6.7 * 10^{-16}$ at 1s of averaging. Moving towards continuous-wave superradiance promises to further improve the short-term frequency stability by orders of magnitude. A key challenge in realizing a cw superradiant laser is the continuous supply of cold atoms into a cavity, while staying in the collective strong coupling regime.

We demonstrate continuous loading and transport of cold ^{88}Sr atoms inside a ring cavity, after several stages of laser cooling and slowing. We further describe the emergence of zones of collective continuous lasing of the atoms on the 7.5kHz transition, 7x narrower than the cavity linewidth, and pumped by the cooling lasers via inversion of the motional states. The lasing is supported by self-regulation of the number of atoms inside the cavity that pins the dressed cavity frequency to a fixed value over >2MHz of raw applied cavity frequency. In the process up to 80% of the original atoms are expelled from the cavity.

Q 18.2 Tue 11:30 HS 1221

Using multifrequency light for large cold atom traps — •David Johnson, Ben Hopton, Nathan Cooper, and Lucia Hackermüller — University of Nottingham, Nottingham, UK

Magneto-optical trapping (MOT) and Bose-Einstein-Condensates (BECs) are used for a wide range of applications, such as sensors for magnetic or gravitational fields, as well as to test fundamental questions such as Quantum Gravity. Larger atom clouds would allow for more precise sensors and test a larger range of parameters of such theories. One limitation to the size of the trapped cold atom cloud is the range of atom velocities that can be addressed by the trapping beams. By using multiple frequencies each shifted by approximately 5MHz, we expect an increase of the atom loading rate by a factor of 1000 or more, thus leading to trapping 10-100 times more atoms in our MOT. A dark spot MOT can be used to reduce the influence of collisional losses and fully demonstrate the feasibility of our proposal.

Q 18.3 Tue 11:45 HS 1221

Dipole trapping of mercury — •Sascha Heider, Thorsten Groh, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nußallee 12, 53115 Bonn, Germany

Mercury is the heaviest, non-radioactive laser-coolable element in the periodic table. With seven naturally occuring isotopes and deep UV transitions (185 nm) suitable for high resolution imaging, mercury is a promising candidate for realizing a future multipurpose quantum gas machine.

We already achieved laser cooling of all seven isotopes on the $^1S_0 \rightarrow {}^3P_1$ (254 nm) transition to sub-Doppler temperatures and high atom numbers [PRA 105, 033106].

For further cooling we currently deploy a high power optical dipole trap (300 W at 1070 nm) to overcome the very low polarizability.

Q 18.4 Tue 12:00 HS 1221

Towards light scattering experiments in dense dipolar gases — •Ishan Varma, Marvin Proske, Rhutwik Sriranga, and Patrick Windpassinger — Institute of Physics, JGU Mainz

Dysprosium is a fascinating candidate for studying cooperative and collective effects in dense ultra-cold media. With the largest ground state magnetic moment of all elements in the periodic table (10 Bohr-magnetons), it offers a platform to study light scattering in a system where magnetic dipole-dipole interactions (DDI) and light induced correlations are in mutual competition. At sufficiently high atomic densities, the strong magnetic DDI significantly influence the propagation of light within the sample. In particular, we want to look at signatures of collective light scattering phenomena like super- and subradiance.

This talk reports on the progress made in generating dense samples of ultracold dysprosium atoms. We plan to optically transport atoms into a home-built science cell with high optical access. The creation and imaging of dense atomic samples inside the science cell is achieved using high NA custom objectives, designed and assembled in-house. We present the performance characterization and discuss the development of these objectives in our experimental system. Further, an outlook is given on future measurements exploring collective and cooperative effects in the generated sample.

Q 18.5 Tue 12:15 HS 1221

Report on the construction of a new Erbium-Lithium machine — •Alexandre De Martino, Florian Kiesel, Kirill Karpov, Jonas Auch, and Christian Gross — Eberhard Karls Universität Tübingen, Physikalisches Institut, AG Groß, Auf der Morgenstelle 14, 72076 Tübingen

Fermionic gases are notoriously difficult to cool down below 10% of the Fermi temperature with usual methods. Pushing the temperature limit and producing colder gases is becoming essential for the study of strongly correlated systems. Sympathetic cooling with a classical gas as an entropy reservoir may provide a new direction to overcome the current limit.

Here we report on the ongoing development of a new Erbium-Lithium machine, whose purpose is to optimize the cooling of an ultracold Lithium gas with an Erbium reservoir. This mixture has several promising features, that have not yet been utilized for sympathetic cooling in other quantum mixtures.

Q 18.6 Tue 12:30 HS 1221

ORKA - Towards a cavity enhanced Optical Dipole Trap for evaporative cooling of Rb87 in microgravity — •Jan Eric Stiehler, Marius Prinz, Marian Woltmann, and Sven Herrmann — Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Germany

Evaporative cooling in optical traps is a common method to prepare ultra-cold quantum gases and generate Bose Einstein condensates (BEC). This usually comes at the prize of an increased power budget for the trapping laser. For setups that require to be energy efficient e.g. in space, magnetic chip traps are thus often preferred. However, these also come with certain limitations and lack some of the benefits of all-optical trapping and cooling. As an alternative we are investigating the use of a resonantly enhanced optical dipole trap for Rb87 to mitigate the power needs of all-optical evaporative cooling. We plan to employ a bow-tie cavity for evaporative cooling to a BEC, to be used as a matterwave source for interferometry in free fall experiments at the the Bremen Gravitower Pro facility. In this talk we will discuss the trade-off for our trapping scheme and present the resulting experiment design as well as simulation results for the bow-tie cavity trap. The ORKA project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50 WM 2267.

Q 18.7 Tue 12:45 HS 1221

Confinement Induced Resonances in Spherical Shell Traps — •C. Moritz Carmesin[1] and Maxim A. Efremov[2,1] — [1]Institute of Quantum Physics and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89081 Ulm, Germany — [2]German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

We have computed exactly the energy spectrum and corresponding wave functions of two bosonic particles, which are confined in a spherically symmetric shell-shaped trap of the radius r_0 and interact with each other via a three-dimensional zero-range potential characterized by the s-wave scattering length a_0. Confinement induced resonances (CIRs) are found to occur at certain values of r_0 and a_0 as avoided crossings between the bound (molecular) and trap (non-molecular) states, as well as between two trap states. The found CIRs originate entirely from the strong coupling of the relative and center-of-mass motions of the two particles. By working close to a CIR, that is at a certain shell radius and a given scattering length, these results offer a new way to increase the atom-atom interaction and even to drive the formation of molecules in the shell-shaped atomic gas.

Q 19: Ultracold Molecules and Precision Spectroscopy (joint session MO/Q)

Time: Tuesday 11:00–13:00 Location: HS 3044

Q 19.1 Tue 11:00 HS 3044

Laser cooling of Barium Monofluoride — •Sebastian Alejandro Morales Ramirez[1], Marian Rockenhäuser[1], Felix Kogel[1], Phillip Gross[1], Tatsam Garg[1], and Tim Langen[1,2] — [1]5. Physikalisches Institut, Universiäat Stuttgart, Pfaffenwaldring 57, 70569, Stuttgart, Germany — [2]Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria

Laser cooling of molecules has made remarkable progress over the last years, and a wide variety of molecular species from diatomics to polyatomics can now be routinely cooled. Recently, significant efforts have been made to add barium monofluoride (BaF) to the list of laser-coolable species, as this molecule shows great promise for various precision measurement applications and cold chemistry. Here, we report on the first experimental realization of Sisyphus cooling of such BaF molecules. Our progress is enabled by high resolution absorption spectroscopy of BaF's intricate level structure and a detailed modelling of the resulting cooling forces. In order further unterstand also the collisional properties of BaF, we perform simultaneous absorption spectroscopy of BaF and calcium monofluoride (CaF) molecules. This gives valuable insights into the thermalisation processes occuring inside a cryogenic buffer gas cell.

Q 19.2 Tue 11:15 HS 3044

Towards a MOT of AlF molecules — •Sid Wright — Fritz-Haber-Institut der Max Planck Gesellschaft, Berlin

Aluminium monofluoride (AlF) is a promising candidate for laser cooling and trapping. The primary laser cooling transition at 227.5 nm is extremely strong and highly vibrationally diagonal, making it feasible to slow a molecular beam from 200 m/s to rest in around 1 cm. This offers the potential to greatly increase the number and density of molecules available for ultracold experiments.

In this talk, I will present the latest progress towards a magneto-optical trap (MOT) of AlF molecules, focusing on the first laser slowing results, and our development of a slow, continuous molecular beam source.

Q 19.3 Tue 11:30 HS 3044

Low-energy collisions between two indistinguishable tritium-bearing hydrogen molecules: HT+HT and DT+DT — •Renat Sultanov — Odessa College, Department of Mathematics — 201 W. University Blvd. Odessa, TX 79764 USA

Elastic and rotational energy transfer collisions between two tritium-containing hydrogen molecules are computed at low- and very low energies, down to ultra-cold temperatures: $T \simeq 10^{-8}$ K. A pure quantum-mechanical approach is applied. A high-quality global six-dimensional potential energy surface (PES) has been appropriately modified and used in these calculations. In the case of the symmetrical H_2+H_2 or D_2+D_2 collisions one can use the original H_4 PES as it is, i.e. without transformations. However, in the case of the non-symmetrical (or symmetry-broken) HD+H_2/D_2, HT+HT, DT+DT scattering systems one should also apply the original H_4 potential (PES), but propagation (solution) of the Schrödinger equation runs (in this case) over the corrected Jacobi vector [1,2].

1. R. A. Sultanov, D. Guster, S. K. Adhikari, Phys. Rev. A 85, 052702 (2012).

2. R. A. Sultanov, D. Guster, S. K. Adhikari, J. Phys. B 49 (2016) 015203.

Q 19.4 Tue 11:45 HS 3044

First laser spectroscopy of a rovibrational transition in the molecular hydrogen ion H_2^+ — •Magnus Roman Schenkel, Soroosh Alighanbari, and Stephan Schiller — Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany

The molecular hydrogen ion H_2^+ is the simplest molecule and has been the subject of innumerous theoretical studies, culminating in highly precise predictions of its level energies [1]. Comparisons of these predictions and measured transition frequencies would offer excellent opportunities in fundamental physics that go beyond the results achieved with the related HD^+ [2]: a direct determination of the proton-electron mass ratio. In this work we report the first vibrational laser spectroscopy of para-H_2^+ between low-lying rovibrational levels [3]. We observed a first overtone electric quadrupole (E2) transition at 2.4 μm and determined its spin-averaged frequency with 1.2×10^{-8} fractional uncertainty, finding agreement with theory. By using HD^+ as a test molecule, we also show that E2 spectroscopy is possible with 1×10^{-12} uncertainty. This demonstrates that determining m_p/m_e spectroscopically with competitive accuracy is a realistic prospect.

This work has received funding from DFG and NRW via grants INST-208/774-1 FUGG, INST-208/796-1 FUGG and from the ERC (grant No. 786306, *PREMOL*).

[1] V. I. Korobov and J.-P. Karr, Phys. Rev. A 104, 032806 (2021).
[2] S. Alighanbari et al., Nat. Phys. 19, 1263 (2023).
[3] M. R. Schenkel et al., Nat. Phys., to appear (2023).

Q 19.5 Tue 12:00 HS 3044

Frequency metrology system for spectroscopy of molecular hydrogen ions in ALPHATRAP — •V. Vogt[1], I.V. Kortunov[1], K. Singh[2], A. Kulangara Thottungal George[2], B. Tu[2,3], C.M. König[2], F. Raab[2], J. Morgner[2], T. Sailer[2], V. Hahn[2], F. Heisse[2], M. Bohman[2], K. Blaum[2], S. Sturm[2], and S. Schiller[1] — [1]Institut für Experimentalphysik, Univ. Düsseldorf, 40225 Düsseldorf — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [3]Institute of Modern Physics, Fudan University, Shanghai 200433

At MPIK, an experiment is in preparation aiming at ultra-high precision vibrational spectroscopy of single molecules H_2^+ and HD^+ in the Penning-trap apparatus ALPHATRAP. We require laser light at $1.1\,\mu$m and $5.48\,\mu$m, respectively, with linewidth 10 Hz, instability below 1 Hz, and absolute frequency measurement capability with uncertainty below 10^{-13}. In addition the laser light must be available 24/7, tunable and switchable under computer control so as to implement appropriate molecule interrogation schemes. We have developed a laser system, similar to [1,2], consisting of spectroscopy laser, reference cavity, transfer laser, frequency comb, hydrogen maser and GNSS receiver at the U. Düsseldorf and transferred it to MPIK, where it has been put into operation again and refined. To transport the spectroscopy light to the Penning-trap, optical fibers with path length cancellation will be implemented. We report the current performance of the system and discuss whether it satisfies the requirements of the experiment.

[1] I. V. Kortunov et al., Nat. Phys. 17, 569 (2021)
[2] S. Alighanbari et al., Nat. Phys. 19, 1263 (2023)

Q 19.6 Tue 12:15 HS 3044

Photodissociation spectrum of a single trapped CaOH+ — •Zhenlin Wu, Stefan Walser, Brandon Furey, Mariano Isaza-Monsalve, Elyas Mattivi, René Nardi, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria

Molecular ions can be sympathetically cooled and crystallized in atomic ion crystals confined in radio-frequency traps, which are ideal for molecular spectroscopy on the single molecule scale. Their application in quantum technologies and the exploration of fundamental physics have also been proposed and demonstrated. Most experiments investigating the internal structure of trapped molecular ions rely on dissociation-based state detection methods and quantum logic spectroscopy via co-trapped atomic qubit ions. In our setup, we aim to study triatomic CaOH+ molecular ions generated in trapped Ca+ ion experiments in the presence of water vapor. As the first step towards quantum logic spectroscopy of a single trapped polyatomic ion, we investigate the single-photon and two-photon photodissociation process of CaOH+ which excites the molecule to its unbound first electronic excited state. We report the photodissociation cross section spectrum of CaOH+ obtained from measurement of a single CaOH+ located in an ion chain. This result can be the basis of dissociation-based spectroscopy for studying the rovibrational structure of CaOH+. In addition, the reported spectrum can be useful in large-scale trapped Ca+ quantum experiments for recycling Ca+ ions when they form undesired CaOH+ ions via background gas collisions.

Q 19.7 Tue 12:30 HS 3044

Collisional shift and broadening of Rydberg states in thermal nitric oxide — •Alexander Trachtmann[1], Fabian Munkes[1], Patrick Kaspar[1], Florian Anschütz[1], Philipp Hengel[2], Yannick Schellander[3], Patrick Schalberger[3], Norbert Fruehauf[3], Jens Anders[2], Robert Löw[1], Tilman Pfau[1], and Harald Kübler[1] — [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

We report on the collisional shift and line broadening of Rydberg states in nitric oxide (NO) with increasing density of a background gas at room temperature [1]. As a background gas we either use NO itself or nitrogen (N2). The precision spectroscopy is achieved by a sub-Doppler three-photon excitation scheme with a subsequent readout of the Rydberg states realized by the amplification of a current generated by free charges due to collisions. [1] arXiv:2310.18256

Q 19.8 Tue 12:45 HS 3044

Highly-resolved Stark effect measurements of Rydberg states in thermal nitric oxide — •Fabian Munkes[1], Alexander Trachtmann[1], Matthew Rayment[2], Florian Anschütz[1], Ettore Eder[1], Yannick Schellander[3], Philipp Hengel[4], Patrick Schalberger[3], Norbert Fruehauf[3], Jens Anders[4], Robert Löw[1], Tilman Pfau[1], Stephen Hogan[2], and Harald Kübler[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK — [3]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Allmandring 3b, 70569 Stuttgart — [4]Institut für Intelligente Sensorik und Theoretische Elektrotechnik, Universität Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart

We demonstrate Stark effect measurements at room temperature of high-lying Rydberg states in nitric oxide. These states are generated using a three-photon continuous-wave excitation scheme. The readout is based on the detection of charged particles created by collisional ionization of Rydberg molecules. A theoretical discussion of the obtained experimental results is given.

Q 20: Quantum Many-Body Dynamics

Time: Tuesday 11:00–13:00 Location: HS 3118

Q 20.1 Tue 11:00 HS 3118

Loss-tolerant photonic fusion networks for quantum computing with quantum emitters — •Matthias C. Löbl, Stefano Paesani, and Anders S. Sørensen — Center for Hybrid Quantum Networks (Hy-Q), The Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark

Graph states are entangled states that enable measurement-based quantum computing, an approach that is particularly promising for architectures using photons as qubits. However, generating the required large photonic graph states is complicated by photon losses and the fact that photon-photon gates are difficult to realize. To generate large graph states, we consider an approach that connects small graph resource states by probabilistic entangling gates (Bell measurements called fusions). To make the scheme practical, we use resource states that are locally equivalent to GHZ states and readily can be generated using quantum emitters. Furthermore, we consider fusion networks where all fusions are performed at once which is advantageous as it minimizes the required adaptiveness and the need for long memory time. We optimize the tolerance to photon loss of several such schemes where either purely photonic graph states or spin-photon entangled states are used. The latter approach is particularly suited for quantum emitters with a spin degree of freedom and we find a tolerance to photon loss of more than 6% for such architectures [1]. Finally, we also discuss algorithms to simulate the photon loss threshold as a non-standard percolation model.

[1] Matthias C. Löbl et a., arxiv:2304.03796 (2023)

Q 20.2 Tue 11:15 HS 3118

Quantum stochastic resetting in lattices with long-range hopping — •Sayan Roy[1], Shamik Gupta[2], and Giovanna Morigi[1] — [1]Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbrücken, Germany — [2]Department of Theoretical Physics, Tata Institute of Fundamental Research, 1 Homi Bhabha Road, Mumbai, 400005, India

Stochastic resetting [1] is considered an efficient strategy for spatial search. The corresponding quantum dynamics is a lively area of research [2]. In this work, we analyze the dynamics of a quantum particle on a one-dimensional lattice with long-range hopping. The hopping decays with the distance as $1/r^{\alpha}$. The particle is additionally subject to repeated projective measurements by a detector placed at the target site and, in case of negative result, it is reset with constant rate to the initial site. We determine the hitting time of the target as a function of α and find the optimal resetting rate required to maximize the detection probability. We further consider the effect of box disorder on the hopping rate and assess the speed of the convergence time as a function of the disorder strength.

[1]. M.R. Evans and S.N. Majumdar, Phys. Rev. Lett. 106, 160601 (2011). [2]. R. Yin, E. Barkai, Phys. Rev. Lett. 130, 050802 (2023).

Q 20.3 Tue 11:30 HS 3118

Topological Quantum Optics in Atomic Emitter Arrays — •Jonathan Sturm and Adriana Pálffy — Julius-Maximilians-Universität Würzburg

Quantum emitter arrays are a powerful platform enabling tailored control of quantum optical phenomena, like super- and subradiance or efficient photon storage [1]. Since state-of-the-art experimental techniques allow the realization of almost arbitrary lattice structures, a natural question is what physical effects arise if the lattice has nontrivial topology.

Here, we study a one-dimensional chain of quantum emitters implementing the Su-Schrieffer-Heeger model. Going beyond previous studies [2], we show how the presence or absence of topologically protected edge states depends on the orientation of the transition dipole moment with respect to the chain axis. Moreover, we discuss how the deliberate breaking of inversion and sublattice symmetry gives rise to non-Hermitian topological states and the emergence of the non-Hermitian skin effect [3]. Our results demonstrate the potential of atomic emitter arrays as a platform for topological quantum optics.

[1] M. Reitz *et al.*, PRX Quantum **3**, 010201 (2022).
[2] B. X. Wang and C. Y. Zhao, Phys. Rev. A **98**, 023808 (2018).
[3] E. J. Bergholtz *et al.*, Rev. Mod. Phys. **93**, 015005 (2021).

Q 20.4 Tue 11:45 HS 3118

Exploring the phase structure of the three-flavor Schwinger model in the presence of a chemical potential with measurement- and gate-based quantum computing — •Stephan Schuster[1], Stefan Kühn[2], Lena Funcke[3], Tobias Hartung[4], Marc-Oliver Pleinert[1], Joachim von Zanthier[1], and Karl Jansen[2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany — [2]CQTA, Deutsches Elektronen-Synchrotron DESY, Platanenallee 6, 15738 Zeuthen, Germany — [3]Transdisciplinary Research Area "Building Blocks of Matter and Fundamental Interactions" (TRA Matter), University of Bonn, Bonn, Germany — [4]Northeastern University - London, Devon House, St Katharine Docks, London, E1W 1LP, United Kingdom

We propose an variational quantum eigensolver (VQE) ansatz, allowing us to explore the phase structure of the multi-flavor Schwinger model in the presence of a chemical potential. The ansatz can incorporate relevant model symmetries via constrains on the variational parameters, and can be implemented on circuit-based as well as measurement-based quantum devices. Classical simulations of the VQE show that our ansatz captures the phase structure of the model, and can approximate the ground state to a high level of accuracy. Moreover, proof-of-principle simulations on a superconducting, gate-based quantum hardware allow to determine the critical points in the considered region of the phase diagram with very good precision.

Q 20.5 Tue 12:00 HS 3118

Quantum state preparation via engineered ancilla resetting — Daniel Alcalde Puente[1], Felix Motzoi[1], Tommaso Calarco[1,2,3], Giovanna Morigi[4], and •Matteo Rizzi[1,2] — [1]Institute of Quantum Control, Peter Grünberg Institut (PGI-8) - Forschungszentrum Julich GmbH, Jülich, Germany — [2]Institute for Theoretical Physics - University of Cologne, Köln, Germany — [3]Dipartimento di Fisica e Astronomia - Universita di Bologna, Bologna, Italy — [4]Theoretical Physics - Saarland University, Saarbrucken, Germany

In this study, we investigate a quantum resetting protocol for preparing ground states of frustration-free Hamiltonians. The protocol uses a steering Hamiltonian for local coupling to ancillary degrees of freedom, which are periodically reset. For short reset times, the dynamics resemble a Lindbladian with the target state as its steady state. We use Matrix Product State simulations and quantum trajectory methods to assess the protocol's efficiency in preparing the spin-1 Affleck-Kennedy-Lieb-Tasaki state, focusing on convergence time, fidelity, and energy evolution at various reset intervals. Our findings indicate that entanglement with the ancillary system is crucial for rapid convergence, with an optimal reset time for peak performance. The protocol also demonstrates robustness against small deviations in reset time and dephasing noise. Our results suggest that quantum resetting could be more advantageous than other methods like quantum reservoir engineering in certain contexts.

Q 20.6 Tue 12:15 HS 3118

Decoding the projective transverse field Ising model — •Felix Roser, Hans Peter Büchler, and Nicolai Lang — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, 70550 Stuttgart, Germany

The competition between non-commuting projective measurements in discrete quantum circuits can give rise to entanglement transitions. It separates a regime where initially stored quantum information survives the time evolution from a regime where the measurements destroy the quantum information. Here we study one such system - the projective transverse field Ising model - with focus on its capabilities as a quantum error correction code. The idea is to interpret one type of measurements as errors and the other type as syndrome measurements. We demonstrate that there is a finite threshold below which quantum information encoded in an initially entangled state can be retrieved reliably. In particular, we implement the maximum likelihood decoder to demonstrate that the error correction threshold is distinct from the entanglement transition. This implies that there is a finite regime where quantum information is protected by the projective dynamics, but cannot be retrieved by using syndrome measurements.

Q 20.7 Tue 12:30 HS 3118

Antiferromagnetic bosonic t-J models and their quantum simulation — •Timothy J. Harris[1,2], Ulrich Schollwöck[1,2], Annabelle Bohrdt[2,3], and Fabian Grusdt[1,2] — [1]Department of Physics and Arnold Sommerfeld Center for Theoretical Physics (ASC), Ludwig-Maximilians-Universität München, 80333 München, München, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Institut für Theoretische Physik, Universität Regensburg, 93035 Regensburg, Germany

Understanding the microscopic origins of the competition between spin and charge degrees of freedom is a central challenge at the heart of strongly correlated many-body physics. Recently, the combination of optical tweezer arrays with systems exhibiting strong interactions, such as Rydberg atoms or ultracold polar molecules, has opened the door for quantum simulation platforms to explore a wide variety of spin models. A significant next step will be the combination of such settings with mobile dopants, in order to study the physics of doped quantum magnets. Here we present recent numerical results from large-scale density matrix renormalization group (DMRG) calculations investigating the phase diagram of the bosonic t-J model with cylindrical boundary conditions at low doping. By introducing antiferromagnetic (AFM) couplings between neighbouring spins, we realize competition between the charge motion and magnetic order similar to that observed in high-Tc cuprates.

Q 20.8 Tue 12:45 HS 3118

Non-Hermitian study of driven-dissipative topological semimetals — •Daniel Borrero Landazabal[1,2], Flore K. Kunst[2], and Sharareh Sayyad[2] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Wilhem-Runge-Str. 10, 89081 Ulm, Germany — [2]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany.

One of the intriguing lines of research in recent years in quantum physics is probing, manipulating, and optimizing topological phases under the influence of ultrafast laser pulses. While in most cases the topological systems are theoretically treated as closed systems, explaining and interpreting some of recent experimental observations were not viable without incorporating the formulation of open quantum systems. Of particular interest is understanding 3D Weyl and Dirac semimetals, like the TaAs, as well as chiral topological semimetals like the RhSi, due to their particularities in electron transport phenomena. In this project, we investigate such systems in a driven-dissipative configuration. To achieve this, we employed various techniques from open quantum systems and non-Hermitian physics. Using these methods, we could evaluate the dynamics of the density matrix, explore its relaxation dynamics, and characterize the topological nature of the system with nonzero dissipation. In particular, we explored the low-energy ($\mathbf{k}\cdot\mathbf{p}$) models of the TaAs and the RhSi compounds and implemented an effective non-Hermitian model. A key result is the discovery of exceptional points (EPs) of high order in the complex spectrum of the two compounds.

Q 21: Quantum Communication III

Time: Tuesday 11:00–13:00 Location: HS 3219

Q 21.1 Tue 11:00 HS 3219

Polarization entanglement in whispering gallery resonators — •Sheng-Hsuan Huang[1,2], Thomas Dirmeier[1,2], Golnoush Shafiee[1,2], Kaisa Laiho[3], Dmitry Strekalov[1], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [3]German Aerospace Center (DLR e.V.), Institute of Quantum Technologies, Ulm, Germany

Cavity-assisted spontaneous parametric down conversion (SPDC) sources are a key component to connect different nodes in quantum networks. Sources based on crystalline whispering gallery mode resonators (WGMRs) have been shown to be capable of generating SPDC states that are both narrow-band and single mode[1,2] and interacting efficiently with alkali atoms[3]. However, to our knowledge, polarization entanglement hasn't been demonstrated in WGMRs.

In our work, we demonstrate the generation of polarization entangled states from a WGMR in an interferometric scheme[4]. Using non-local two-photon interference effects, we demonstrate the generation of genuine entangled states. We also evaluate the S parameter of the CHSH inequality to be 2.45 ± 0.07, which violates the inequality by more than six standard deviations.

[1]J. U. Fürst, et al., Physical review letters 104.15 153901 (2010)
[2]M. Förtsch, et al., Nature communications 4.1 (2013)
[3]G. Schunk, et al., Optica 2.9 (2015)
[4]S-H. Huang, et al., arXiv preprint arXiv:2310.16589 (2023).

Q 21.2 Tue 11:15 HS 3219

Generation of indistinguishable single photons from a single ^{40}Ca^{+}-ion using short laser pulses — •Pascal Baumgart, Max Bergerhoff, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Hong-Ou-Mandel interference on a beam splitter, a key step in quantum repeater schemes involving entanglement swapping, requires indistinguishability of single photons [1]. A commonly used method to create single photons from single atoms is continuous laser excitation of a Λ-type Raman transition. This renders indistinguishability difficult, as multiple back-decays and re-excitations on the driven transition, governed by the branching ratio of the excited state, lead to an uncertainty in the photon emission time [2]. An alternative approach that limits the number of back-decays is excitation by short laser pulses, on the order of the excited state lifetime. Using a Raman transition in a single trapped ^{40}Ca^{+}-ion with an excited state lifetime of 7 ns, we investigate the feasibility of this approach. We present an experimental setup to generate few-nanosecond laser pulses at the excitation wavelength of 393 nm, and we examine the dependence of the photon purity on the pulse length and amplitude.

[1] T. van Leent et al., Nature 607, 2022
[2] P. Müller et al., Phys. Rev. A 96, 2017

Q 21.3 Tue 11:30 HS 3219

Phase stabilization for high bandwidth fiber-based continuous variable quantum key distribution — •Sophie Verclas, Benedict Tohermes, and Roman Schnabel — Institut für Quantenphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Deutschland

Quantum Key Distribution (QKD) is a technology for secure communication between two parties, using the principles of quantum mechanics. Our QKD experiment implements a fiber-based, continuous variable QKD scheme, connecting two laboratories in two separated buildings (building A and B). We set up an EPR entanglement source in building A, consisting of two squeeze lasers and overlapped their outputs at a 50/50 beamsplitter to generate two-mode squeezed states, which are shared between the two buildings via optical fiber.

In both buildings, the entangled states are measured with balanced homodyne detectors. Due to the entanglement, the results are random but also correlated and can be used to generate a secret key. Attacks on the channel as well as on devices in building B reduce the entanglement strength and can thus be quantified.

A major challenge in this setup is the phase stabilization and synchronization between the two buildings. In this presentation I will introduce the experiment, discuss the problem of phase noise and our approach to a control scheme for its compensation.

Q 21.4 Tue 11:45 HS 3219

Controlling individual erbium dopants in silicon — •Johannes Früh[1,2], Andreas Gritsch[1,2], Alexander Ulanowski[1,2], Fabian Salamon[1,2], Adrian Holzäpfel[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

Erbium dopants are promising candidates for the implementation of large-scale quantum networks since they can combine second-long ground state coherence (1) with coherent optical transitions at telecommunication wavelengths. So far, the long lifetime of the excited state made it difficult to spectrally resolve and control individual ions in order to harness them for quantum networks. To overcome this challenge, we embed erbium dopants into silicon photonic crystal resonators (2) and Fabry-Perot resonators (3) with small mode volume, which facilitates the direct comparison of the two approaches. While the nanophotonic resonators give Purcell enhancements up to 170, the Fabry Perot geometry avoids the proximity of interfaces and thus offers better optical coherence and narrower spectral diffusion linewidths down to 3 MHz. Reducting the latter down to lifetime limit, this approach is thus promising towards the entanglement of remote dopants.

(1) M. Rancic, M. P. Hedges, R. L. Ahlefeldt, M. J. Sellars, Nat. Phys. 14, 50 (2018)
(2) A. Gritsch, A. Ulanowski, A. Reiserer, Optica 10, 783-789 (2023)
(3) A. Ulanowski, B. Merkel, A. Reiserer, Sci. Adv, 8 (2022)

Q 21.5 Tue 12:00 HS 3219

Spectroscopy and cavity-enhanced emission of Eu-based molecular systems — •Evgenij Vasilenko, Vishnu Unni C, Weizhe Li, Nicholas Jobbitt, Senthil Kuppusamy, Mario Ruben, and David Hunger — Karlsruhe Institute of Technology

Rare-earth ions in solid-state hosts are a promising candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. Recently, also REI-based molecular complexes have shown excellent optical coherence properties [1]. However, Eu ions have a long optical lifetime of the ^{5}D$_{0}$-^{7}F$_{0}$ transition ($T_{1,opt}\sim$ ms) and a low branching ratio (< 1%), limiting single-ion experiments. Both issues can be solved by high-finesse fiber-based microcavities. We study Eu-doped molecular crystalline materials, including a Trensal complex that yields 7 min spin lifetime and a homogeneous linewidth of 2.8 MHz at 4.2 K [2]. On a single, macroscopic molecular crystal [Eu(Ba)4(pip)] [1], we measure narrow inhomogeneous linewidths, hour-long spin T_1 and photon echoes at < 1K. Steps to integrate molecular crystals into a fiber cavity at cryogenic operation are reported. Open-access fiber cavities have been demonstrated to achieve high quality factors and low mode volumes, while simultaneously offering large tunability and efficient collection of the cavity mode [3]. The results are important steps towards single-ion readout and control being necessary for scalable quantum registers.

[1] Serrano et al., Nature, 603, 241-246 (2022)
[2] Kuppusamy et al., J. Phys. Chem. C 127, 22 (2023)
[3] Hunger et al., New J. Phys 12, 065038 (2010)

Q 21.6 Tue 12:15 HS 3219

Frequency Conversion in a high pressure hydrogen gas — •Anica Hamer[1], Priyanka Yashwantrao[1], Seyed Mahdi Razavi Tabar[1], Alireza Aghababaei[1], Frank Vewinger[2], and Simon Stellmer[1] — [1]Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany — [2]Institut für Angewandte Physik, Wegelerstraße 8, Universität Bonn

Quantum networks, as envisioned for quantum computation and quantum communication applications, are based on a hybrid architecture. Such a layout may include solid-state emitters, network nodes based on single or few atoms or ions, and photons as so-called flying qubits. This concept requires an efficient and entanglement-preserving exchange of photons between the individual components, which often entails frequency conversion of the photon.

Our approach is based on coherent Stokes and anti-Stokes Raman scattering (CSRC and CARS) in dense molecular hydrogen gas. This four-wave mixing process sidesteps the limitations imposed by crystal properties, it is intrinsically broadband and does not generate an undesired background. We have demonstrated conversion between 434 nm (F donors in ZnSe) to 370nm (Yb^+ ions) and between 863 nm (InAs/GaAs quantum dots) and the telecom O-band. We will present first steps towards integrated frequency conversion in gas-filled hollow-core fibers.

Q 21.7 Tue 12:30 HS 3219

Co-doping a Crystalline Membrane for Improved Spectral Multiplexing of Rare-earth Emitters — Alexander Ulanowski[1,2], Johannes Früh[1,2], •Fabian Salamon[1,2], Adrian Holzäpfel[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Technische Universität München, TUM School of Natural Sciences, James-Franck-Straße 1, 85748 Garching, Germany

Erbium dopants in solids exhibit a coherent optical transition at a telecommunication frequency and spin coherence times exceeding a second. This offers an exceptional potential for extended quantum networks [1].

To realise an efficient spin-photon interface, a 10 μm thin crystalline membrane is embedded into a Fabry-Perot resonator. The narrow optical transitions of the emitters then allow for spectral multiplexing [2]. In this context, we show that the spectral density and thus the number of individually resolvable qubits can be tailored by co-doping an erbium-doped YSO crystal with europium [3]. Using this technique, more than 360 emitters with an optical coherence that reaches the lifetime limit can be optically resolved with Purcell factors up to 110.

These advances constitute a key step towards large-scale multiplexed entanglement generation for a global quantum network.

[1] A. Reiserer, Rev. Mod. Phys. 94, 041003 (2022). [2] A. Ulanowski, B. Merkel & A. Reiserer, Sci. Adv. 8, eabo4538 (2022). [3] A. Ulanowski, J. Früh, F. Salamon, A. Holzäpfel & A. Reiserer, arXiv:2311.16875 (2023).

Q 21.8 Tue 12:45 HS 3219

A compact and portable room temperature atomic vapor quantum memory — •Alexander Erl[1,2], Martin Jutisz[3], Elisa Da Ros[3], Luisa Esguerra[2,1], Leon Messner[2], Mustafa Gündoğan[3], Markus Krutzik[3,4], and Janik Wolters[2,1] — [1]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Berlin — [3]Humboldt-Universität zu Berlin, Institut für Physik, Berlin — [4]Ferdinand-Braun-Institut, Institut für Hochstfrequenztechnik, Berlin

In recent years, considerable progress has been made in the field of room temperature quantum memories. The inherent simplicity of this platform makes it very promising for use outside of laboratory environments, including in space-based applications. As an essential component of quantum repeaters, space-compatible memories could advance global quantum communication networks [1]. Here we present the implementation and performance analysis of a portable rack-mounted system, operated inside and outside of lab environment. This optical memory utilizes a lambda-scheme based on the Cesium D_1 line transitions at 895 nm [2]. We achieve internal memory efficiencies of >40% for storage times of 500 ns. Employing attenuated coherent pulses, we observe storage and retrieval fidelities exceeding the classical threshold [3].

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)
[2] L. Esguerra et al., Phys. Rev. A 107, 042607 (2023)
[3] M. Jutisz et. al., in preparation (2024)

Q 22: Members' Assembly

Time: Tuesday 13:15–14:15 Location: HS 1199

All members of the Quantum Optics and Photonics Division are invited to participate.

Q 23: Poster I

Time: Tuesday 17:00–19:00 Location: Tent B

Q 23.1 Tue 17:00 Tent B

Continuous entanglement generating superradiant SU(4) laser — Jarrod Reilly[1], •Gage Harmon[2], John Wilson[1], Murray Holland[1], and Simon Jäger[3] — [1]University of Colorado Boulder — [2]Saarland University — [3]University of Kaiserslautern-Landau

We present a cross-cavity system in which steady-state superradiance is achieved with solely collective dissipative dynamics. The cavities symmetrically couple an ensemble of four-level atoms by driving transitions between two electronic and two motional states. We demonstrate that the system continuously generates both interparticle entanglement between the constituent particles and intraparticle entanglement between the internal and external degrees of freedom. We use innovative techniques to examine the two types of entanglement and, remarkably, we find that the system in steady-state is Heisenberg limit scaled with nearly maximal entanglement entropy between the internal and external degrees of freedom. Lastly, we discuss potential applications of our proposed model to the prominent fields of quantum metrology and quantum information science.

Q 23.2 Tue 17:00 Tent B

Speeding Up Squeezing with a Periodically Driven Dicke Model — Jarrod T. Reilly[1], •Simon B. Jäger[2], John D. Wilson[1], John Cooper[1], Sebastian Eggert[2], and Murray J. Holland[1] — [1]JILA, NIST, and Department of Physics, University of Colorado Boulder — [2]Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau

We present a simple and effective method to create highly entangled spin states on a faster timescale than that of the commonly employed one-axis twisting (OAT) model. We demonstrate that by periodically driving the Dicke Hamiltonian at a resonance frequency, the system effectively becomes a two-axis countertwisting Hamiltonian which is known to quickly create Heisenberg limit scaled entangled states. For these states we show that simple quadrature measurements can saturate the ultimate precision limit for parameter estimation determined by the quantum Cramér-Rao bound. An example experimental realization of the periodically driven scheme is discussed with the potential to quickly generate momentum entanglement in a recently described experimental vertical cavity system. We analyze effects of collective dissipation in this vertical cavity system and find that our squeezing protocol can be more robust than the previous realization of OAT.

Q 23.3 Tue 17:00 Tent B

Quantum Master Equation for Self-organization in Cavity QED — •Tom Schmit[1], Simon Jäger[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

Ensembles of atoms strongly coupled with the electric field of an optical cavity offer a formidable laboratory for studying the out-of-equilibrium dynamics of long-range interacting systems in the quantum regime. In this work, we extend the theoretical framework of Refs. [1,2] to derive a unifying quantum master equation describing cavity cooling and self-organization of atomic ensembles in high-finesse resonators. Our approach is valid for a broad range of parameters, from temperatures of laser-cooled atoms to the ultra-cold quantum degenerate regime. We discuss in detail the validity of our description as a function of the cavity's detuning and lifetime. At ultra-low temperatures, the model predicts that the coupling with the dissipative resonator gives rise to an effective, long-range decoherence that tends to heat up the atoms. We determine the dynamics for a small system and analyse the effect of long-range cavity-induced dissipative forces on metastability.

[1] S. Schütz, H. Habibian, and G. Morigi, Phys. Rev. A **88**, 033427 (2013).
[2] S. B. Jäger, T. Schmit, G. Morigi, M. J. Holland, and R. Betzholz, Phys. Rev. Lett. **129**, 063601 (2022).

Q 23.4 Tue 17:00 Tent B

A Tensor Network Perspective on the Micromaser — •Andreas J. C. Woitzik[1], Edoardo Carnio[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg im Breisgau, Federal Republic of Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Freiburg im Breisgau, Federal Republic of Germany

The one-atom (or micro-) maser – in which a stream of (Rydberg) atoms interacts sequentially and in resonance with a quantized mode of a high-quality cavity – is a pioneering experiment on the interaction between light and matter at the level of single quanta, and the archetypal quantum collision model. Our contribution introduces a tensor network model for the micromaser that represents the incoming atomic string as a Matrix Product State (MPS). We leverage the tensor network formalism, employing a DMRG-like optimization technique, to identify optimal atomic strings to prepare the cavity in a sought-after target state. When the target state of the cavity is a Fock state, we find an analytic relation between its Fock number and the bond dimension of the optimal MPS.

Q 23.5 Tue 17:00 Tent B

Quantum optics model mapping for thin-film x-ray cavities — •Julien Spitzlay[1], Hanns Zimmermann[1,2], Fabian Richter[1], and Adriana Pálffy[1] — [1]Julius-Maximilians-Universität Würzburg — [2]Universität der Bundeswehr München

Thin-film cavities with one or several embedded layers of Mössbauer nuclei are promising platforms for the quantum control of x-ray photons. At grazing incidence, incoming resonant x-rays couple evanescently to the cavity, while the resulting cavity field drives the nuclear transitions. Several quantum optics models have been developed in the past decade to describe the resonant x-ray scattering in these nanostructures, for instance a cavity QED model [1] or an ab-initio formalism based on the electromagnetic Green's function [2,3].

In this work we investigate parallels between the x-ray thin-film cavity models and well-known quantum optics models for coherent phenomena in few-level systems such as electromagnetically induced transparency (EIT) or Autler-Townes-Splitting (ATS). The aim is to identify parameter regimes where thin-film x-ray cavities can display a behaviour reminiscent to these phenomena and the relations between the coupling constants of the respective underlying quantum optics models.

[1] K. Heeg and J. Evers, Phys. Rev. A 88, 043828 (2013)
[2] D. Lentrodt, K. Heeg, C. H. Keitel, J. Evers, Phys. Rev. Research 2, 023396 (2020)
[3] X. Kong, D. Chang, A. Pálffy, Phys. Rev. A 102, 033710 (2020)

Q 23.6 Tue 17:00 Tent B

Coupled states of cold Yb atoms in a high-finesse cavity — •Saran Shaju, Dmitriy Sholokhov, Simon B Jäger, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

We study the atom-cavity interaction of cold Yb atoms inside a 5-cm long optical high-finesse cavity that is resonant with its $^1S_0 \rightarrow {}^3P_1$ intercombination transition at 556 nm wavelength. The atoms are magneto-optically trapped and cooled on their $^1S_0 \rightarrow {}^1P_1$ transition at 399 nm. We record the cavity output as well as the free-space fluorescence when a probe on $^1S_0 \rightarrow {}^3P_1$ drives the cavity on axis. By varying the cavity and probe frequency, we observe coupled atom-cavity states with atom number-dependent splitting. We associate the observation to the existence of collective strong coupling of the atoms with the single mode of the resonator. We extend our understanding by simulating the problem using a quantum mechanical mean-field model.

Q 23.7 Tue 17:00 Tent B

Chiral cavities: an extendible and simple theoretical model — •Carlos Bustamante, Dominik Sidler, Michael Ruggenthaler, and Angel Rubio — Max Planck Institute for the Structure an Dynamics of Matter, Hamburg, Germany.

Over the past decade, we have witnessed a huge growth in cavity quantum electrodynamics phenomena. This growing interest is centered around the formation of polaritons in these cavities –a hybrid quantum state resulting from the strong interaction between light and matter. Polaritons' hybrid nature offers a new alternative to change matter properties by tailoring light. For instance, it is possible to impart spin-angular momentum on photon modes to get circularly polarized light (CPL). Cavities capable of confining CPL are known as chiral cavities. Despite the absence of experimental results, some theoretical studies have already shown that this kind of cavities could be useful in chemistry. However, the simulations conducted thus far are quite challenging due to the necessity of employing beyond-dipole approximations and high levels of accuracy. In this work, we propose a chiral cavity Hamiltonian derived using dipole approximation and a hybrid gauge. To test this Hamiltonian, we worked with a one-dimensional atom, placed in a spring topology, in order to get a chiral symmetry. The results demonstrate that, despite some limitations of the model, our Hamiltonian can capture properties dependent on the polarization of the cavity or the chirality of the matter system. The simplicity of our Hamiltonian offers an efficient way to explore the fundamental physical properties of these systems.

Q 23.8 Tue 17:00 Tent B

Towards deterministic strong coupling between single trapped atoms and a Whispering-Gallery-Mode microresonator — •xinxin hu, luke masters, gabriele maron, arno rauschenbeutel, and juergen volz — Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany

In the past decades, coupling between single trapped atoms and high Q factor microresonators has been a strong research focus because a resonator can significantly enhance of light-atom interaction and realize strong coupling. More recently, aided by the progress of materials and microfabrication technology, more integratable resonator types, e.g. photonic crystal cavities and optical nanofiber-based cavities, have been explored in single-atom CQED systems, and many breakthroughs have been achieved in such systems. Of particular interest are whispering-gallery-mode resonators, such as microsphere or microtoroid resonators that exhibit extremely high Q-factors exceeding 10^9. Here, we present the work of our group towards deterministic strong coupling of single trapped atoms to a bottle-type WGM microresonator. In our experiment we load a single atom from a magneto optical trap into an optical tweezer. Subsequently, using a focus tunable lens, we move the trapped atoms over a distance of ~1mm into the evanescent field of the WGM resonator. We will report on the efficiency of the atom transport close to and into the evanescent field of the resonator.

Q 23.9 Tue 17:00 Tent B

Design and realization of a high-finesse optical resonator for cavity-assisted readout of atomic arrays — •Jacopo De Santis[1,2], Mehmet Öncu[1,2], Balázs Dura-Kovács[1,2], Sebastian Ruffert[1,2], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany

The ability to read out a subset of a quantum register during the execution of an algorithm is a fundamental ingredient for fault tolerant quantum computation. But for this mid-circuit measurement to be effective, it should satisfy some specific requirements: be fast compared to the qubit decoherence time, have low error rates and be nondestructive of the qubits which are not being read out. However, free space measurements of qubits encoded in neutral atoms are rather slow, or destructive of nearby atoms due to the heating associated with scattered photons. Coupling an atomic array to a high-finesse optical resonator is a promising solution to these problems: thanks to the Purcell effect, not only can we detect a higher fraction of the fluoresced photons, but the directionality of the emission makes it less likely for the scattered photons to be reabsorbed by other atoms in the array. In this poster I will focus on the design criteria for such a cavity and describe how it can be used for qubit readout. Lastly, I will present some of the more practical aspects in the realization of a high-finesse optical resonator. In particular, I will introduce the setup I developed for testing and assembling a near-concentric cavity with cooperativity $C \geq 7$.

Q 23.10 Tue 17:00 Tent B

A cavity-integrated microwave antenna for spin manipulation of Nitrogen-Vacancy center in diamond — •Andras Lauko[1], Kerim Köster[1], Jeremias Resch[1], Julia Heupel[2], Cyril Popov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, DE — [2]Universität Kassel, Kassel, DE

In the competitive field of research for the realization of a quantum repeater, nitrogen-vacancy color centers in diamonds are a promising candidate for their optically addressable spin states. A possible platform to enhance the spin-photon interactions is an optical fiber based, tuneable Fabry-Perot cavity, allowing for an open access to the sample. This motivates the integration of a microwave antenna into the resonator, combining the sophisticated coherent control of the spin states of the nitrogen-vacancy center with the benefits provided by the cavity, namely the spatially and spectrally improved emission.

This work arrives at the cavity-integrated microwave antenna in two stages. First, a widely used antenna design, called the wire loop antenna design is modified and fabricated. Then the antenna is integrated into a confocal microscopy setup and experiments involving the measurement of Rabi oscillations are presented.

Lastly, the antenna is mounted into an optical fiber-based microcavity and Rabi frequencies surpassing 10 MHz are measured. The optical performance is unaffected by the antenna and the thermal effects on the cavity caused by the microwave excitation are investigated.

Q 23.11 Tue 17:00 Tent B

Self-consistent Red Shift – an Alternative Feature of Light-matter Coupling? — •Jacob Horak, Dominik Sidler, Michael Ruggenthaler, and Angel Rubio — Max Planck Institute for the Structure and Dynamics of Matter and Center for for Free-Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany

Polaritonic chemistry is a new field which was established when experiments showed a change in chemical reactivity merely due the different electromagnetic environment inside an optical cavity. The effect is attributed to the formation of hybrid particles, polaritons, made up of a molecular excitation strongly coupled to the resonance mode of a cavity. Compared to an empty cavity, resonances are always shifted depending on the filling and this has been used to monitor the progress of reactions, e.g, with IR spectroscopy.[1]

Here, we show that an analytic expression of the self-consistent red shift derived from the Pauli-Fierz Hamiltonian for harmonic molecules deviates from the Lorentz model. Traditionally, observing a Rabi split, i.e., the energy separation between the polaritons, has been the hallmark of experimentally quantifying light-matter coupling. Could measuring the red shift become another avenue to monitor strong light-matter coupling experimentally?

[1] A. Thomas, J. George, A. Shalabney, M. Dryzhakov, S. J. Varma, J. Moran, T. Chervy, X. Zhong, E. Devaux, C. Genet, J. A. Hutchison, T. W. Ebbesen, *Angew. Chem. Int. Ed.* **2016**, 55, 11462-11466.

Q 23.12 Tue 17:00 Tent B

Spectral properties of a cold-atom laser — Dmitriy Sholokhov, Saran Shaju, •Ke Li, and Jürgen Eschner — Universität des Saarlandes

We investigate optical gain and lasing emission from an ensemble of a few thousand Ytterbium-174 atoms which are magneto-optically trapped, using the $^1S_0$ - $^1P_1$ transition at 399 nm, inside a 5-cm long high-finesse cavity. When the atoms are pumped on the $^1S_0$ - $^3P_1$ intercombination transition at 556 nm, continuous-wave lasing on the same transition is observed [1]. By heterodyne analysis, we measure the cavity output spectra for a range of trap and pump light powers and detuning. From the data, we extract the gain profile for the cold ytterbium laser and compare its properties with our theoretical model.

Q 23.13 Tue 17:00 Tent B

A Superradiant Gas of Driven-Dissipative Two-Level Atoms as a Source of Non-Classical Light — •Christopher Mink and Michael Fleischhauer — University of Kaiserslautern-Landau, Kaiserslautern, Germany

Motivated by the recent experimental observation of non-Gaussian correlations in the light emitted by a driven-dissipative cigar shaped cloud of two-level atoms [Ferioli et. al, arXiv:2311.13503] we theoretically investigate the dynamics and steady state properties of this system using a dissipative extension of the well-established Discrete Truncated Wigner Approximation. This allows us to determine the interatomic correlations as well as the radiated light field and its symmetrically ordered first and second order correlation functions $g^{(1)}(\tau)$ and $g^{(2)}(\tau)$. We verify a violation of the Siegert relation for the light emitted along the main axis of the cloud. Furthermore we show that in the steady state the atoms emit a negligible electric field which therefore does not contribute to the reduction of $g^{(2)}(\tau)$. This is instead due to non-Gaussian statistics. Finally, the Wigner function of the radiated field is extracted and the quadratures are investigated to demonstrate generation of non-classical light.

Q 23.14 Tue 17:00 Tent B

Optimal control of arbitrary perfectly entangling gates for open quantum systems — •Adrian Köhler and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

Perfectly entangling gates (PE) are crucial for various applications in quantum information. One method to realize these gates is with the help of an external control field, whose concrete shape is found using optimal control theory. Instead of optimizing the shape that realizes a specific gate, the optimization target can be extended to the full set of PE. This increases the flexibility of optimization and allows to find the best PE from the set of all PE. For unitary dynamics, the PE optimization functional can readily be evaluated. In contrast, for non-unitary dynamics, one has to approximate the unitary part of the dynamics first. We employ this technique to superconducting qubits, where we apply a cross-resonant drive to two coupled fixed-frequency transmons to generate entangled states.

Q 23.15 Tue 17:00 Tent B

A graph-based approach to dissipative production of multipartite entangled states in trapped ions — •Antoine Guinchard, Karl Horn, Daniel Reich, and Christiane Koch — Freie Universität Berlin, Berlin, Deutschland

Entanglement is a key ingredient for quantum technologies. We study the creation of entangled states on trapped ion qubits, where logical states are encoded in the ionic hyperfine states which are coupled via common vibrational modes. By leveraging dissipative processes in this system, schemes to generate both two- and three-partite entanglement have recently been developed by Karl P Horn et al [2018 New J. Phys. 20 123010] and Daniel C Cole et al [2021 New J. Phys. 23 0730].

We developed a graph-theoretical approach which allows us to find dissipative protocols to generate entangled states in a computationally efficient way by representing the population flow on the logical state space. This method allows us to both reproduce the previously derived protocols for the three-qubit case and even find entirely new schemes. By adding an extra transition per qubit, we are able to show that one of our new schemes is scalable to an arbitrary number of qubits. Due to the graph-based and system-agnostic nature of our method, our protocols can be generalised to a wide variety of experimental setups.

Q 23.16 Tue 17:00 Tent B

Role of dephasing in optimal transport of spin excitations in a two-dimensional, lossy lattice — •Andrei Skalkin, Razmik Unanyan, and Michael Fleischhauer — RPTU, Kaiserslautern

Noise is commonly regarded as an adverse effect disrupting communication and limiting efficiency of many processes. However, it has been shown [P. Rebentrost et al., New Journal of Physics 11, 2009] that decoherence processes can play a significant role in quantum transport facilitation. We study how a dephasing noise, acting on all sites with equal rate, improves spin excitation transport efficiency in a two-dimensional lattice with dipole-dipole long-range interaction. We provide a new mechanism of dephasing-assisted transport in ordered systems. The study includes both numerical and analytical approaches and may serve as a benchmark for experiments in the framework of optical lattices.

Q 23.17 Tue 17:00 Tent B

Fermionic coherent state path integral for ultrashort laser pulses and transformation to a field theory of coset matrices including disorder-noise — •Bernhard Mieck — Keine Institution

A coherent state path integral of anti-commuting fields is considered for a two-band, semiconductor-related solid including an ensemble-average with disorder-noise. A ultrashort, classical laser field is the driving source term for the initial states. We describe the generation of exciton quasi-particles from the driving laser field as anomalous pairings of the fundamental, fermionic fields. This gives rise to Hubbard-Stratonovich transformations from the quartic, fermionic interaction to various Gaussian terms of self-energy matrices; the latter self-energy matrices are solely coupled to bilinear terms of anomalous-doubled, anti-commuting fields which are subsequently removed by integration and which create the determinant with the one-particle operator and the prevailing self-energy. We accomplish path integrals of even-valued self-energy matrices with Euclidean integration measure where three cases of increasing complexity are classified (scalar self-energy variable, density-related self-energy matrix and also a self-energy including anomalous doubled terms). The SSB is performed with hinge-fields which factorizes the total self-energy matrix by a coset decomposition into density-related, block diagonal self-energy matrices of a background functional and into coset matrices with off-diagonal block generators for the anomalous pairings of fermions. This allows to derive a classical field theory for the self-energy matrices.

Q 23.18 Tue 17:00 Tent B

Selfconsistent diagrammatic transport for light includingtime reversal symmetric entropy production — •Regine Frank[1,2] and Bart A. van Tiggelen[3] — [1]College of Biomedical Sciences, Larkin University, Miami, Florida, USA — [2]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain — [3]University Grenoble Alpes, Centre National de la Recherche Scientifique, LPMMC, Grenoble, France

We present novel theory and numerics for transport of light in random complex media, where the production of entropy is positive under time reversal, an Onsager scenario. Time and space resolved numerical solutions based on weighted essentially non-oscillatory solvers (WENO) are introduced and discussed with respect to Anderson localization. [1] R. Frank, A. Lubatsch, Phys. Rev. Research 2, 013324 (2020). [2] D. Vollhardt and P. Woelfle, Phys. Rev. B 22, 4666 (1980). [3] P. D. Lax and R. D. Richtmyer, Commun. Pure Appl. Math. 9, 267 (1956). [4] A. Lubatsch, J. Kroha, K. Busch, Phys. Rev. B.71, 184201 (2005) [5] R. Frank, A. Lubatsch, J. Kroha, Phys. Rev. B 73, 245107 (2006). [6] B. A. van Tiggelen, A. Lagendijk, and A. Tip, Phys. Rev. Lett.71, 1284 (1993). [7] B. A. Van Tiggelen, Diffuse Waves in ComplexMedia, 1-60 (1999)

Q 23.19 Tue 17:00 Tent B

A vacuum-integrated fiber cavity setup for characterizing Q-optimized polymer-based mechanical resonators — •Florian Giefer, Daniel Stachanow, Lukas Tenbrake, Sebastian Hofferberth, and Hannes Pfeifer — Institute of Applied Physics, University of Bonn, Germany

Optomechanical platforms with high-quality mechanical and optical resonators have a wide application potential ranging from quantum limited sensing to long-lived storage of quantum information. Whilst exceptionally high quality factors have been realized with structures in thin layers of dielectric or semiconducting materials, their geometries are limited by the capacity of lithographic fabrication. Recent developments in polymer-based 3D direct laser-written structures allow for new paradigms in manufacturing micromechanical resonators, but so far suffer from strong mechanical dissipation. We show viable routes for improving this platform, including dissipation dilution, and present a scanable vacuum-integrated fiber cavity setup for probing high quality-factor mechanical resonators. To interface resonators we build a platform for flexible cavity construction between a fiber mirror and a DBR substrate in vacuum. Compared to previous designs, we improved the locking quality and flexibility of the optical cavity and added several additional features. Using this tool, optimized mechanical resonators and multi-resonator structures will be investigated in the near future.

Q 23.20 Tue 17:00 Tent B

Otto cycles with a quantum rotor as the working medium — •Michael Gaida and Stefan Nimmrichter — Universität Siegen, Deutschland

Quantum rotors possess genuine features such as a non-uniform energy level spectrum and quantum revivals under free rotation. Experimental progress in levitated optomechanics has made the orientation of anisotropic nanoparticles amenable to optical control and cooling and promises to reach the quantum regime in the near future. We investigate how the working regimes of an Otto engine changes due to quantum effects. As the main result we present two Otto cycles with a planar rotor as the working medium. We distinguish between the three operation modes Engine, refrigerator and heater. A comparison of a quantum rotor with its classical counterpart reveals significant changes in the operation regimes: While one of the presented Otto cycles shows genuine quantum disadvantage, the other becomes only useful in the quantum case.

Q 23.21 Tue 17:00 Tent B

Controlled phonon dynamics in optomechanical systems — •Victor Ceban — Institute of Applied Physics, Moldova State University, Academiei str. 5, Chisinau, Moldova

There is a plethora of quantum optic phenomena enabling the control of the spontaneous emission effect, which results in suppression or increase of the spontaneous emission decay rate. Here, we show that this kind of phenomena can be explored in order to control the phonon behaviour in an optomechanical setup. Namely, the phonons seams to follow the changes introduced to the population decay dynamics of a considered emitter. Two different open quantum systems are presented.

In the first case, long-lived phonons are obtained when slowing-down the atomic decay of an emitter. An optomechanical setup made of an aromatic molecule embedded within an organic crystal is considered. Spontaneous emission suppression is achieved by placing the setup in a cavity and by modulating the emitter*s transition frequency. This effect becomes prominent for mechanical resonators with high damping rates, such as organic crystals.

In the second case, fast phonon dynamics is obtained when superradiant conditions are considered. An optomechanical system made of a collection of closely-spaced quantum dots placed on a vibrating membrane is considered. The quantum dot sample exhibits superradiance features which are transferred to the phonon dynamics

Q 23.22 Tue 17:00 Tent B

Enhancing the purity of single photons in parametric down-conversion through simultaneous pump-beam and crystal-domain engineering — •Baghdasar Baghdasaryan[1], Fabian Steinlechner[1,4,5], and Stephan Fritzsche[1,2,3] — [1]FSU Jena — [2]HI Jena — [3]TPI Jena — [4]Fraunhofer IOF, Jena — [5]IAP Jena

Spontaneous parametric down-conversion (SPDC) has shown great promise in the generation of pure and indistinguishable single photons. Photon pairs produced in bulk crystals are highly correlated in terms of transverse space and frequency. These correlations limit the indistinguishability of photons and result in inefficient photon sources. Domain-engineered crystals with a Gaussian nonlinear response have been explored to minimize spectral correlations. Here we study the impact of such domain engineering on spatial correlations of generated photons. We show that crystals with a Gaussian nonlinear response reduce the spatial correlations between photons. However, the Gaussian nonlinear response is not sufficient to fully eliminate the spatial correlations. Therefore, the development of a comprehensive method to minimize these correlations remains an open challenge. Our solution to this problem involves simultaneous engineering of the pump beam and crystal. We achieve purity of single-photon state up to 99% without any spatial filtering. Our findings provide valuable insights into the spatial waveform generated in structured SPDC crystals, with implications for applications such as boson sampling.

Q 23.23 Tue 17:00 Tent B

Weyl su(3) diamonds are knit and woven — •Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie

Multiplets of the symmetry groups SU(2) (rotations) and SU(3) (color or flavour symmetry) are well-known examples where the abstract theory of group representations (actually of the Lie algebra) provides an organising viewpoint for physical applications [1]. We discuss an explicit algorithm that constructs the matrices that represent the su(3) generators in an arbitrary irreducible representation [2]. They can be visualised with the help of "ladder operators" (also known as "roots" in representation theory) that map one basis state to another one. The two-dimensional multiplets of su(3) (quark triplets, meson octets or a baryon decuplets, for example) "hide" certain selection rules for the ladder operators that can be visualised intuively in a three-dimensional projection: multiplets become polyhedra that look like diamonds.

[1] Hermann Weyl, *Gruppentheorie und Quantenmechanik* (Hirzel 1928)

[2] S. Coleman, Fun with SU(3), in: High-Energy Physics and Elementary Particles, (IAEA proceedings, Vienna 1965), pp331–52

Q 23.24 Tue 17:00 Tent B

Direct measurement of pseudothermal light violating Siegert relation — •Xi Jie Yeo[1], Mingze Qing[1], Justin Peh[1], Darren Koh[1], Jaesuk Hwang[1], Christian Kurtsiefer[1,2], and Peng Kian Tan[1] — [1]Centre for Quantum Technologies, Singapore, Singapore — [2]National University of Singapore, Singapore, Singapore

We present a technique to directly measure the violation of Siegert relation, relating the first and second order photon correlation of thermal light. Specifically, we extract correlations between photoevents detected at the output ports of an asymmetric Mach-Zehnder interferometer. Using this technique, we observe a violation of Siegert relation by laser light scattered off a rotating ground glass, while Siegert relation is obeyed for light from a mercury vapor lamp.

Q 23.25 Tue 17:00 Tent B

Dimensional Reduction in Quantum Optics — •Jannik Ströhle and Richard Lopp — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany

One-dimensional quantum optical models usually rest on the intuition of large scale separations associated with the different spatial dimensions, for example when studying quasi one-dimensional atomic motion, potentially resulting in the violation of $3+1$D Maxwell's theory. In this paper, we provide a rigorous foundation for this approximation by means of the light-matter interaction. We show how the quantized electromagnetic field can be decomposed – without approximation – into an infinite number of one-dimensional *subfields* when studying axially symmetric setups, such as a fiber cavity, a laser beam or a waveguide. The *dimensional reduction* approximation then corresponds to a truncation in the number of such subfields that in turn, when considering the interaction with for instance an atom, corresponds to an approximation to the atomic spatial profile. We explore under what conditions the standard dimensional reduction approximation of a single subfield is justified, and when corrections are necessary in order to account for the dynamics due to the neglected spatial dimensions. In particular we will examine what role vacuum fluctuations play in the validity of the approximation.

Q 23.26 Tue 17:00 Tent B

Influence of direct dipole-dipole interaction on the optical response of 2D materials in inhomogeneous infrared cavity fields — •Sofia Ribeiro[1,2], Javier Aizpurua[2], and Ruben Esteban[2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Centro de Física de Materiales, Centro Mixto CSIC-UPV/EHU, Donostia, Spain

The interaction between light and matter can be strongly enhanced by using nanophotonic cavities that localize light at the nanoscale. Our work considers a 2D material formed, by a self-assembled molecular monolayer or by a single layer of a Van der Walls material, coupled to an infrared nanophotonic cavity, potentially reaching the strong coupling regime. Important effects can arise from the direct dipole-dipole interactions between the molecules, such as the emergence of new collective modes. The main effect of considering direct dipole-dipole interactions on the optical properties of the hybrid system for homogeneous or slowly varying cavity fields is the renormalization of the effective energy of the bright collective mode of the 2D material that couples with the nanophotonic mode. However, we find that, for situations of extreme field confinement, fully including the direct interactions within the 2D material becomes critical to correctly capture the optical response, with many collective vibrational states participating in the response. Further, we derive a simple analytical equation which establishes the criteria for the need of dipole-dipole interactions in the description of the hybrid system beyond the standard renormalization.

Q 23.27 Tue 17:00 Tent B

Wave-particle duality in weighted two-way interferometers: Which-way knowledge increase via delayed observable choice — •Elisabeth Meusert, Marc-Oliver Pleinert, and Joachim von Zanthier — Quantum Optics and Quantum Information Group, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany

The concept of wave-particle duality lies at the heart of quantum mechanics and appears, for example, in Young's well-known double slit experiment. There, the simultaneous observations of a visible interference pattern and the acquisition of which-way knowledge about the photon's path are limited by an inequality, dubbed the duality relation. Previous studies on symmetric interferometers showed that the obtained which-way knowledge can be correlated to the quantum object's phase for certain observables, and used this phase-dependency to increase the which-way knowledge above the duality relation-limit via delayed observable choice.

Our studies generalize these findings to arbitrarily weighted interferometers. We find again that the now weight- and phase-dependent which-way knowledge can be increased beyond the duality-relation limit. Moreover, we find that specific observables provide the highest improvement in which-way knowledge at asymmetric interferometer weights. These findings suggest that both the maximum achievable which-way knowledge and the highest possible knowledge increase might be available in unbalanced interferometers, at a value not obtainable from symmetry arguments.

Q 23.28 Tue 17:00 Tent B

Many-particle coherence and higher-order interference — •Marc-Oliver Pleinert[1], Eric Lutz[2], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information Group, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany — [2]Institute for Theoretical Physics I, University of Stuttgart, 70550 Stuttgart, Germany

Quantum mechanics is based on a set of only a few postulates, which can be separated into two parts: one part governing the inner structure, i.e., the definition and dynamics of the state space, the wave function and the observables; and one part making the connection to experiments. The latter is known as Born's rule, which simply put relates detection probabilities to the modulus square of the wave function. The resulting structure of quantum theory permits interference of indistinguishable paths; but, at the same time, limits such interference to certain interference orders. In general, quantum mechanics allows for interference up to order 2M in M-particle correlations. Depending on the mutual coherence of the particles, however, the related interference hierarchy can terminate earlier. Here, we show that mutually coherent particles can exhibit interference of the highest orders allowed. We further demonstrate that interference of mutually incoherent particles truncates already at order M+1 although interference of the latter is principally more multifaceted. Finally, we demonstrate the disparate vanishing of such higher-order interference terms as a function of coherence in experiments with mutually coherent and incoherent sources.

Q 23.29 Tue 17:00 Tent B

Quantum dynamics of nuclear many-body systems driven by an XFEL — •Miriam Gerharz and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Ensembles of Mössbauer nuclei form a promising platform for quantum optics in extreme parameter regimes because of their narrow transitions in the hard x-ray regime. These narrow transitions feature long lifetimes, which results in the system being essentially decoherence free. However, because of those narrow resonances at synchrotrons on average there is less than one resonant photon per pulse. This situation has recently changed with first experiments at X-ray free electron lasers (XFEL), where there are up to hundreds of resonant photons per pulse, such that qualitatively new regimes of higher nuclear excitations can be explored. Here we present recent progress in the theoretical modelling of the dissipative nuclear many-body dynamics after XFEL excitation.

Q 23.30 Tue 17:00 Tent B

A Fiber-based Microcavity Platform to Purcell-enhance Diamond Color Centers — •Yanik Herrmann[1], Julius Fischer[1], Julia M. Brevoord[1], Stijn Scheijen[1], Colin Sauerzapf[1,2], Leonardo G. C. Wienhoven[1], Laurens J. Feije[1], Matteo Pasini[1], Martin Eschen[1,3], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2628 CJ Delft, The Netherlands — [2]Present address: 3rd Institute of Physics and Research Center SCoPE, University of Stuttgart, 70049 Stuttgart, Germany — [3]Netherlands Organisation for Applied Scientific Research (TNO), P.O. Box 155, 2600 AD Delft, The Netherlands

Quantum networks are promising both for applications like secure communication and for basic science tests of quantum mechanics at a large scale. Color centers in diamond, like the Nitrogen- or Tin-Vacancy center are excellent node candidates, because of their optically accessible spin with a long coherence time, but the collection of coherent photons is limited. Integration into an optical cavity can boost both the coherent emission via the Purcell effect and the collection efficiency due to a well-defined cavity mode. Here we present a low temperature platform, which is in particular designed to provide a low vibration level while maintaining high flexibility over the cavity and fiber control. Such a system is expected to significantly speed up entanglement rates in present day networks, a critical step towards large scale quantum networks with solid state emitters.

Q 23.31 Tue 17:00 Tent B

Recent developments on microfabricated Penning trap electrodes for matter-antimatter comparison tests. — •Nima Hashemi[1,2,3], Julia-Aileen Coenders[1,2], Jacob Stupp[1,2], Friederike Giebel[3], Jan Schaper[1,2], Juan Manuel Cornejo[1,2], Stefan Ulmer[4,5], and Christian Ospelkaus[1,2,3] — [1]Leibniz

Universität Hannover, Germany — [2]LNQE, Hannover, Germany — [3]Physikalisch Technische Bundesanstalt, Braunschweig, Germany — [4]Ulmer Fundamental Symmetries Laboratory, Riken, Japan — [5]Heinrich-Heine-Universität Düsseldorf, Germany

Penning ion traps have proven to be an excellent tool for g-factor comparison tests of matter and antimatter in the baryonic sector of the Standard Model [1,2]. At Leibniz University of Hannover, within the BASE collaboration [3], we are working on the development of quantum-logic inspired methods based on Coulomb coupling of single (anti-)protons to a laser-cooled beryllium ion for better particle localization and detection on these g-factor experiments [4]. Microfabricated Penning trap electrodes of $800\,\mu$m inner diameter and a thickness of $200\,\mu$m are necessary to gain full control over the coupling process. A challenging part of the microfabrication are the processes of photolithography because of three-dimensional structures and double-sided geometry of the electrodes. In this contribution recent methods for optimization of these processes are analyzed and evaluated.

[1] G. Schneider et al., Science 358, 1081 (2017) [2] C. Smorra et al., Nature 550, 371 (2017) [3] Eur. Phys. J. Spec. Top. 224, 3055-3108 (2015) [4] Juan M Cornejo et al 2021 New J. Phys. 23 073045

Q 23.32 Tue 17:00 Tent B

Nonlinear characterization of in-house fabricated thin film lithium niobate waveguides — •Alexej Widajko, Laura Bollmers, Harald Herrmann, Laura Padberg, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, D-33098 Paderborn

Thin film lithium niobate (TFLN) is an evolving platform for photonic circuits for different application areas. In particular, the high nonlinearity and the wide transparency range of $LiNbO_3$ together with the tight confinement in nanophotonic waveguides enable the realization of efficient frequency converters e.g. for applications in quantum computing and quantum cryptography.

However, to exploit the full potential of nonlinear TFLN devices the fabrication process, which includes the fabrication of the optical waveguides and the periodic poling for phase-matching of the targeted nonlinear process, must be optimized.

In this work we are focussing on the development of an efficient nonlinear characterization setup for TFLN, which allows to assess the quality of the devices. We primarily use second harmonic generation (SHG) with the fundamental wave in the telecom wavelength range to study the nonlinear properties of in-house fabricated TFLN devices. We give a short overview of the fabrication process, discuss some first results on SHG characterization and initial work on photon pair generation via parametric down-conversion using the fabricated devices.

Q 23.33 Tue 17:00 Tent B

Integrated electro-optic modulators in $LiNbO_3$ as fundamental building blocks for quantum photonic circuits — •Noel Heinen, Michelle Kirsch, Sattibabu Romala, Sebastian Lengeling, Harald Herrmann, Laura Padberg, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Institut für Photonische Quantensysteme, Warburger Str. 100, D-33098 Paderborn

Numerous applications in quantum communication and quantum processing require electric manipulation of photonic quantum states. Thus, electro-optic modulators (EOMs) are key components for photonic integrated circuits (PICs). A suitable and widely used material platform for EOMs is lithium niobate (LN) due to its high electro-optic coefficient and broad transparency window. Recent developments in integrated optics show that thin film lithium niobate (TFLN) is a highly versatile and promising material platform. Due to a drastically higher mode confinement than in titanium indiffused LN waveguides, nonlinear effects and integration density are further enhanced. The increase in modulation efficiency leads to higher modulation speeds and power efficiencies, as lower modulation voltages are required. Therefore programmable circuits for quantum information processing can be realized, as fast modulation is needed. As the fundamental building block of EOMs are phase shifters, we cover the fabrication process of TFLN phase modulators and compare their benefits over conventional diffused LN phase modulators with respect to their optical and electrical properties.

Q 23.34 Tue 17:00 Tent B

***N* Scaling of Large-Sample Collective Decay in Inhomogeneous Ensembles** — Sergiy Stryzhenko[1,2], Alexander Bruns[1], and •Thorsten Peters[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany — [2]Institute of Physics, National Academy of Science of Ukraine, Nauky Avenue 46, Kyiv 03028, Ukraine

We experimentally study collective decay of an extended disordered ensemble of N atoms inside a hollow-core fiber. We observe up to 300-fold enhanced decay rates, strong optical bursts and a coherent ringing. Due to inhomogeneities limiting the synchronization of atoms, the data does not show the typical scaling with N. We show that an effective number of collective emitters can be determined to recover the N scaling known to homogeneous ensembles over a large parameter range. This provides physical insight into the limits of collective decay and allows for its optimization in extended ensembles as used, e.g., in quantum optics, precision time-keeping or waveguide QED.

Q 23.35 Tue 17:00 Tent B

Second-order correlations of scattering electrons — •Florian Fleischmann[1], Mona Bukenberger[2], Raul Corrêa[3], Anton Classen[4], Simon Mährlein[1], Marc-Oliver Pleinert[1], and Joachim von Zanthier[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Quantum Optics and Quantum Information, 91058 Erlangen, Germany — [2]ETH Zürich, Department of Environmental Systems Science, 8092 Zürich, Switzerland — [3]Federal University of Minas Gerais, Departamento de Física, 31270-901 Belo Horizonte, Brazil — [4]University of Utah, Health Science Core, UT 84112 Salt Lake City, USA

We investigate the spatial second-order correlation function of two scattering electrons in the far field. First, we consider semi-classically the effects of the Pauli exclusion principle and Coulomb repulsion on the expected correlation pattern. This is followed by a full quantum-mechanical treatment of the problem. For this, we separate the system into center-of-mass and relative coordinates in analogy to the hydrogen atom ansatz. While the center-of-mass system is described as a free particle, we solve the Coulomb scattering problem in the relative system. We expand the respective initial state of the electrons in the eigenstates of the scattering problem. After incorporating the time evolution, the function is evaluated in the far field. We show the formal solution to the problem and discuss the current state of the numerical investigations.

Q 23.36 Tue 17:00 Tent B

Cryogenic spectroscopy of novel organic molecules doped with Yb3+ for quantum information processing applications — •Robin Wittmann[1], Jannis Hessenauer[1], Sören Schlittenhardt[1], Senthil Kumar Kuppusamy[1], Mario Ruben[1,2], and David Hunger[1] — [1]KIT, Karlsruhe, Germany — [2]CNRS-Université, Strasbourg, France

Rare earth ions (REI) doped into crystals have proven to be a promising system for quantum information processing due to their long optical coherence time stemming from the shielding of the partially filled 4f electron shell by the fully occupied 5s and 5p orbitals. Yb3+ is a REI that is particularly interesting as a microwave to optical photon interface due to it being a Kramers ion with an electron spin of 1/2. Benefits of trivalent Ytterbium are its simple energy level structure consisting of only two electronic multiplets, as well as its favorable branching ratio. In addition, long electron spin coherence times were observed for Yb171 due to its zero magnetic field clock transition in low symmetry crystals. Here we investigate the optical lifetime, coherence time and optical linewidth of novel organic molecules tailored to host REIs. Measurements are done at cryogenic temperatures on ensembles of Yb3+ doped molecular crystal powder to test its viability for quantum information processing tasks. We observe narrow inhomogeneous linewidths and individually addressable subspecies sensitive to different excitation wavelengths.

Q 23.37 Tue 17:00 Tent B

A nanosecond pulsed light source as pump source for narrowband, decorrelated photon pairs — •Jasmin Sommer, Michelle Kirsch, Kai Hong Luo, Harald Herrmann, and Christine Silberhorn — Universität Paderborn, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, D-33098 Paderborn

Narrowband and spectrally decorrelated photon pairs are a prerequisite for many applications in quantum processing. A common way to generate single photon pairs is to use parametric down conversion (PDC) sources. Exploiting clustering within a cavity allows the generation of spectrally narrowband photon pairs. Decorrelated pure states can be further obtained by pumping the source with pulses of well-defined properties. We have developed a pump source dedicated for pumping cavity-enhanced PDC in a periodically poled waveguide in $LiNbO_3$. To generate photon pairs in the telecom range, this requires Gaussian shaped pulses around 775 nm with an adjustable pulse length in the nanosecond range. We have constructed such a pump source starting with a cw laser at 1550 nm. An electro-optical modulator is used to generate specifically tailored pulses of well-defined duration. These are amplified in erbium doped fiber amplifiers and converted to the 775 nm range via second harmonic generation in a periodically poled bulk $LiNbO_3$ crystal. We report details on the design and characterization of the pump source and initial experiments towards the generation of decorrelated photon pairs.

Q 23.38 Tue 17:00 Tent B

Quantum pulse gate conversion efficiency — •Dana Echeverría-Oviedo[1], Hiroko Tomoda[2], Felix Moor[1], Michael Stefszky[1], Benjamin Brecht[1], and Christine Silberhorn[1] — [1]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany. — [2]Department of Applied Physics, School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

The quantum pulse gate (QPG) is a dispersion-engineered guided-wave device, based on sum-frequency generation (SFG) between spectrally shaped light pulses. It can implement time-frequency mode-selective projections of single photons on user-defined modes. These are useful for quantum applications in, e.g., metrology, communications and simulations, where high efficiencies are crucial. The SFG conversion efficiency η, that is the ratio between the number of upconverted photons over the number of input photons (assuming no pump depletion and neglecting propagation losses), is given by $\eta = \sin^2(\sqrt{\eta_{norm} P_p}\, L)$, where η_{norm} is η normalized per pump power P_p and sample length L. Considering identical experimental conditions (geometry and material of the waveguide; spatial, temporal and spectral overlap; and pulse characteristics) to increase η it is necessary to increase L, which is a challenge due to the accumulation of fabrication inhomogeneities of longer samples. In this work, we measured η of a 71 mm long QPG, the longest reported until now, which reaches η of up to 64% for a P_p of only 12.5 mW. Here, we report on the progress of the project.

Q 23.39 Tue 17:00 Tent B

Hong-Ou-Mandel interference in the spectral domain — •Patrick Folge, Abhinandan Bhattacharjee, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

The Hong-Ou-Mandel (HOM) effect describes the quantum interference of indistinguishable photons on a beam splitter, and is one of the most celebrated effects in quantum optics. It provides a fundamental building block of many technological applications, including linear optical quantum computation and (Gaussian) boson sampling. In this work we explore the implementation of HOM type effects in the spectral domain of optical fields, which could help in the efforts of scaling up the dimensionality of the mentioned technologies. Our spectral domain approach achieves the required beam splitter like operation between different frequency bins, using a so called multi-output quantum pulse gate (mQPG). This is a frequency conversion based device, implemented in dispersion engineered $LiNbO_3$ waveguides, which allows to interfere programmable superpositions of frequency bins in different output frequency channels. In our scheme we consider frequency entangled photon pairs generated in a type-0 parametric down conversion source as the input to the frequency beam splitter to observe the bunching in the output channels of the mQPG. Here, we report the progress of this ongoing project.

Q 23.40 Tue 17:00 Tent B

Designing a two-output Quantum Pulse Gate — •Theresa Keuter, Patrick Folge, Laura Serino, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS) Warburger Str. 100, 33098 Germany

Time-frequency modes serve as a versatile basis for numerous quantum technology protocols. Yet, the simultaneous detection of distinct time-frequency modes poses a significant challenge. Addressing this issue, a multi-output quantum pulse gate (mQPG) has recently been implemented, which has the capability to map different time-frequency modes to distinct output frequencies, enabling their separation. The mQPG was implemented in dispersion-engineered periodically poled $LiNbO_3$ waveguides by alternating between poled and unpoled regions, generating multiple phase-matching peaks corresponding to different output frequencies. However, this approach is not optimized for maximal conversion efficiencies due to the presence of unpoled regions in the waveguide. In scenarios where the mQPG operates on quantum states, such as those generated by parametric down conversion, maximizing conversion efficiencies is desireable. Here, we explore an alternative approach by modulating the poling structure with a square wave, which promises higher efficiencies. We focus on the design and optimization of mQPGs with two output channels. We investigate the influence of various parameters on the resulting efficiencies and report on the progress of our ongoing project.

Q 23.41 Tue 17:00 Tent B

Fabrication of a surface-electrode ion trap for quantum information processing — •Nora D. Stahr[1,3], Jacob Stupp[1,3], Eike Iseke[2], Nila Krishnakumar[2], Friederike Giebel[2], Konstantin Thronberens[2], Chloë Allen-Ede[1,3], Amado Bautista-Salvador[2], and Christian Ospelkaus[1,2,3] — [1]Leibniz Universität Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Laboratory of Nano and Quantum-Engineering, Hannover, Germany

Surface-electrode ion traps are a promising platform for the realisation of quantum computers, as the underlying microfabrication techniques are scalable [1]. The MIQRO project is developing surface-electrode ion traps for scalable quantum computers that utilise microwave fields and static magnetic fields for quantum logic gates [2]. For future applications, the number of integrated electrodes needs to be increased and additional functional units are required to be integrated into the ion trap substrates to enable better connectivity and optimised optical access. In addition, the assembly and connection technology needs to be adapted to the increasing requirements. We present microfabrication techniques for the production of multi-layer quantum processor chips [3] with the aim of implementing different technologies in one process flow.

[1] S. Seidelin et al., Physical Review Letters 96, 253003 (2006). [2] F. Mintert, & C. Wunderlich, Physical Review Letters 87, 257904 (2001). [3] A. Bautista-Salvador et al., New Journal of Physics 21, 043011 (2019).

Q 23.42 Tue 17:00 Tent B

Phase transition and higher-order mean-field theory of chiral waveguide QED — •Kasper Jan Kusmierek[1], Max Schemmer[2], Sahand Mahmoodian[3], and Klemens Hammerer[4] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Germany — [2]Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO), 50019 Sesto Fiorentino, Italy — [3]Centre for Engineered Quantum Systems, School of Physics, The University of Sydney, Sydney, NSW 2006, Australia — [4]Institute for Theoretical Physics, Leibniz University Hannover, Germany

Waveguide QED with cold atoms provides a potent platform for the study of non-equilibrium, many-body, and open-system quantum dynamics. Even with weak coupling and strong photon loss, the collective enhancement of light-atom interactions leads to strong correlations of photons arising in transmission. Here we apply an improved mean-field theory based on higher-order cumulant expansions to describe the experimentally relevant, but theoretically elusive, regime of weak coupling and strong driving of large ensembles. We determine the transmitted power, squeezing spectra and the degree of second-order coherence. In the regime of very large drive and atom numbers we observe an non-equilibrium phase transition. This reveals the important role of many-body and long-range correlations between atoms in steady state.

Q 23.43 Tue 17:00 Tent B

Superradiant bursts of light from cascaded quantum emitters: Theoretical modelling of photon-photon correlations — Constanze Bach, Christian Liedl, Arno Rauschenbeutel, Philipp Schneeweiss, and •Felix Tebbenjohanns — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

A fully inverted ensemble of two-level emitters coupled to a common radiation mode emits its energy as a superradiant burst of light [1]. Recently, we have observed experimentally that a similar collective

dynamics prevails in the case of a cascaded quantum system [2]. Due to the large number of up to 1200 emitters, the theoretical modeling of our experiments is challenging. Here, we present two novel numerical models with favorable computational complexity that allow us to quantitatively predict the observed burst dynamics. The first model approximates the light field between adjacent atoms as a probabilistic mixture of coherent states. This mixed coherent state approximation (MCSA) correctly predicts the emitted power and the field-field correlations. In addition, we implement the discrete truncated Wigner approximation, which was recently developed in [3]. This inherently stochastic model agrees with the predictions of our MCSA and additionally computes the photon-photon correlations, in agreement with our experimental data. In the future, we plan to test the applicability of our models to other experiments with cascaded quantum systems.

[1] R. H. Dicke, Phys. Rev. 93, 99 (1954).
[2] C. Liedl et al., arXiv:2211.08940 (2023).
[3] C. D. Mink and M. Fleischhauer, arXiv:2305.19829 (2023).

Q 23.44 Tue 17:00 Tent B

Chromatic suppression of spontaneous emission — •Thomas Lafenthaler[1], Yannick Weiser[1], Tommaso Faorlin[1], Lorenz Panzl[1], Rainer Blatt[1,2], Thomas Monz[1,3], and Giovanni Cerchiari[1,4] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Technikerstrasse 21a, 6020 Innsbruck, Austria — [3]AQT, Technikerstraße 17, 6020 Innsbruck, Austria — [4]Department of Physics, University of Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany

We control the spontaneous emission of trapped Ba+ Ions with reflective boundary conditions. By reflecting the fluorescence light of the ion onto itself, the single photons emitted by the ions interfere with themselves, making it possible to control the emission rate. The control depends on the solid angle in which the emitted photons are retroreflected and, to achieve complete control, we utilize a hemispherical mirror that can oversee the ion from every direction of space. When the mirror radius is adjusted to obtain destructive interference at the emitted photons wavelength, fluorescence, and consequently, the corresponding energy transition, can be suppressed. Here, I present our current effort to control the decay of the $6p_{1/2}$ state of the Ba+ ion which can relax by emitting 493 nm or 650 nm photons. Our aim is to demonstrate control over the decay branching ratio, which could find application in other experiments, for example, to suppress an unwanted relaxation branch or simplify its energy structure.

Q 23.45 Tue 17:00 Tent B

Multi-commodity transport and the role of the dynamical metric — •Joshua Ganz, Giovanna Morigi, and Frederic Folz — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

The interplay of nonlinear dynamics and noise is at the basis of coherent phenomena, such as stochastic resonance, synchronization, and noise-induced phase transitions. While the effect of noise in these phenomena has been partially analyzed, the impact of the specific form of the nonlinear dynamics on noise-induced phase transitions is unknown. In this work, we analyze multi-commodity transport on a noisy network where the nonlinearity enters through a dynamical metric that depends nonlinearly on the local current. We determine network self-organization for different functional forms of the metric in a geometry of constraints simulating two transportation demands. We perform an extensive study of the emerging network topologies for the deterministic case and for the case of adding Gaussian noise to the nonlinear dynamics. To characterize the network topologies, we introduce performance measures such as robustness. We show that the resulting dynamics exhibits noise-induced resonances, which manifest as self-organization into the most robust network with a resonant response to a finite value of the noise amplitude. We analyze in detail the specific features and perform a comparative assessment. Our study sheds light on the interplay between nonlinear dynamics and stochastic forces, highlighting how their joint effect determines noise-induced coherence.

Q 23.46 Tue 17:00 Tent B

Multiwavelength Characterization of Polarization Optics for Broadband Superconducting Detector Calibration — •Isabell Mischke, Timon Schapeler, and Tim Bartley — Institute for Photonic Quantum Systems, Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

Intrinsically, superconducting detectors can detect a broad spectrum. But it remains an open question whether the detector behaves the same to one photon at a certain energy or two photons of half the energy. To investigate the difference in the behaviour, it is important to understand the operation of the detector for different wavelengths. Our aim is the multiwavelength characterization of superconducting nanowire single-photon detectors (SNSPDs), with respect to the polarization and wavelength dependence of the setup. This requires exploring the wavelength and polarization dependence of all components, to extract the intrinsic spectral response of the SNSPD alone. We present initial data towards this aim.

Q 23.47 Tue 17:00 Tent B

Light propagation through ensembles of nuclear two-level systems — •Deniz Adigüzel, Miriam Gerharz, and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Recent experiments at X-ray free electron lasers allow one to access new excitation regimes. The light-matter interactions can be studied by solving the optical-Bloch equations. Observing an ensemble of atoms, the light is scattered off of these atoms either coherently or incoherently. By comparing the intensities of these quantities, one can show that in the low-excitation regime their ratio remains constant in time[1]. However, [1] focused on settings in which propagation effects could be neglected. Here we study the light propagation through an ensemble of atoms beyond the low excitation regime in situations in which propagation effects are of relevance and compare the coherent/incoherent radiation.

[1] L. Wolff and J. Evers. "Characterization and detection method for x-ray excitation of Mössbauer nuclei beyond the low-excitation regime", Physical Review A 108(4), 043714 (2023)

Q 23.48 Tue 17:00 Tent B

Fabrication of Solid Immersion Lenses for the cryogenic Investigation of the NV center — •Judith de Vries, Katharina Senkalla, Stefan Dietel, Michael Olney-Fraser, Lev Kazak, and Fedor Jelezko — Institute for Quantumoptics, Ulm University, Ulm, Germany

The Nitrogen-Vacancy (NV) center in diamond has shown great potential for applications in quantum information processing, sensing, and imaging. A known application of NV center in cryogenic environment is the quantum repeater. As the entanglement rate is limited by the photon-collection efficiency of the NV centers, improving this efficiency through the use of solid immersion lenses can greatly enhance the performance of quantum repeaters. Here we investigate the performance of the fabricated SILs in particular in cryogenic environment.

Q 23.49 Tue 17:00 Tent B

Investigations of fluorescence lifetimes, thermal lensing, and laser performance of directly diode pumped cw ruby laser — Carsten Reinhardt and •Sönke Metelmann — Hochschule Bremen City University of Applied Sciences

Recently, the first laser ever, Maiman*s 694 nm ruby laser, regained new interest due to successful cw operation by pumping with high-power 405 nm laserdiodes [1]. Investigation on compact plane-plane Ruby laser[2] indicate stabilization of the resonator by thermal lensing, induced by the pump laser diode. Here we present results of studies on pump laserdiode performances for optical pumping of ruby crystals. Temperature dependend fluorescence lifetimes have been measured for different pump powers. First results on measurements of thermal lensing are presented. [1] W. Luhs, B. Wellegehausen; Diode pumped cw ruby laser, OSA Continuum 184, Vol.2, No.1 (2019) [2] W. Luhs, B. Wellegehausen; Diode pumped compact single frequency cw ruby laser, J. Physics Communications 7 (2023) 0055007

Q 23.50 Tue 17:00 Tent B

Bridging Quantum Optics and Environmental Physics: Insights into Argon Trap Trace Analysis — •Magdalena Winkelvoss and Alexandra Beikert — Kirchhoffinstitut für Physik Heidelberg

Tracer experiments are an important tool to understand environmental transport processes. A particularly widely used class of tracers are radioactive isotopes, which can be used for dating. ^{39}Ar has a half life of 268 years making it suitable for the time range of 50 to 1000 years and dating processes like ocean circulation or glacier flow. But as the relative abundance of ^{39}Ar is in the range of 10^{-16}, a ultra sensitive and selective detection method is required. This can be done by Argon Trap Trace Analysis (ArTTA), by capturing single ^{39}Ar atoms in a magneto-optical trap (MOT). Here, the slight difference in excitation frequencies between the different isotopes is exploited. In combination with the high number of scattered photons, this gives a high isotopic selectivity and makes ArTTA an ideal method for dating ^{39}Ar.

Opposed to many other atom trapping experiments the amount of ^{39}Ar is limited due to sample size, thus it is important to capture a high percentage of the atoms. With this poster we present the working principle of the ArTTA technique and will highlight the challenges of addressing argon atoms. Specifically, we will address the most crucial challenges of the measurement technique: the atom beam collimation and focusing apparatus to reach a high trapping rate in the MOT.

Q 24: Poster II

Time: Tuesday 17:00–19:00 Location: KG I Foyer

Q 24.1 Tue 17:00 KG I Foyer

Spectroscopy of Heteronuclear Xenon-Noble Gas Dimers - Towards Bose-Einstein Condensation of VUV-Photons — •Eric Boltersdorf, Thilo vom Hövel, Jeremy Andrew Morín Nenoff, Frank Vewinger, and Martin Weitz — University of Bonn, Institute for Applied Physics, 53115 Bonn

Photons confined in a dye-filled optical microcavity can exhibit Bose-Einstein condensation upon thermalization through repeated absorption and (re-)emission processes by the dye molecules. This has been experimentally demonstrated for photons in the visible spectral regime in 2010. In this work, an experimental approach is investigated to realize Bose-Einstein condensation of vacuum-ultraviolet (100 nm-200 nm; *VUV*) photons via repeated absorption and (re-)emission cycles between two electronic state manifolds of xenon-noble gas excimer molecules in dense gaseous ensembles (pressure of up to 100 bar).
(Re-)emission and absorption to achieve thermalization are considered to occur between the quasi-molecular states associated with the xenon $5p^6$ and $5p^5 6s(J = 1)$ states, respectively. We plan to pump the photon gas inside a high-pressure optical microcavity with light at near 129 nm wavelength, which can be generated by third-harmonic generation of near-ultraviolet light around 387 nm. The pump drives the $5p^6 \rightarrow 5p^5 6s'(J = 1)$ transition in xenon. We report on the results of spectroscopic measurements, indicating the formation of heteronuclear noble gas excimers. Also, the fulfillment of the thermodynamic Kennard-Stepanov relation, a fundamental prerequisite for a gas to serve as a thermalization medium, has been successfully investigated.

Q 24.2 Tue 17:00 KG I Foyer

Realization of Effective Interactions in Bose-Einstein Condensates of Photons — •Niels Wolf, Andreas Redmann, Christian Kurtscheid, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn, Germany

Bose-Einstein condensation can be observed with ultracold atomic gases, polaritons, and since about a decade ago also with low-dimensional photon gases. In atomic Bose-Einstein condensates thermal equilibrium is obtained by inter-particle collisions. Since photon-photon interactions remain vanishingly small in the experimental cavity system, thermalization of photons is achieved via thermal contact of the photons with molecules in liquid solution filled into a microcavity [1]. Nevertheless, via strong photon-photon interaction, i.e. a Kerr-interaction, lattices of photon gases could in future enable the creation of highly entangled resource states for multiple partner quantum connectivity [2].

Our experiment uses a triply resonant optical parametric oscillator setup, which independently controls cavities for the pump and subharmonic wavelength respectively. In this way, a Kerr-nonlinearity originating from cascaded second order nonlinearities to subharmonics of the incident optical radiation has been experimentally demonstrated.

[1] J. Klaers et al., Nature 468, 545 (2010) [2] C. Kurtscheid et al., Science 366, 894 (2019)

Q 24.3 Tue 17:00 KG I Foyer

Dimensional Crossover in a Quantum Gas of Light — •Kirankumar Karkihalli Umesh[1], Julian Schulz[2], Julian Schmitt[1], Martin Weitz[1], Georg von Freymann[2,3], and Frank Vewinger[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstrasse 8, 53115 Bonn, Germany — [2]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern Landau, 67663 Kaiserslautern, Germany — [3]Fraunhofer Institute for Industrial Mathematics ITWM, 67663 Kaiserslautern, Germany

We experimentally study the properties of a harmonically trapped photon gas undergoing Bose-Einstein condensation along the dimensional crossover from one to two dimensions. The photons are trapped inside a dye microcavity, where polymer nanostructures provide a harmonic trapping potential for the photon gas. By varying the aspect ratio of the trap we tune from an isotropic two-dimensional confinement to an anisotropic, highly elongated one-dimensional trapping potential. Along this transition, we determine caloric properties of the photon gas, and find a softening of the second-order Bose-Einstein condensation phase transition observed in two dimensions to a crossover behaviour in one dimension.

Q 24.4 Tue 17:00 KG I Foyer

Observation of topological edge states of photons by controlled coupling to the environment — •Nikolas Longen[1], Helene Wetter[2], Michael Fleischhauer[3], Stefan Linden[2], and Julian Schmitt[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [3]Fachbereich Physik, RPTU Kaiserslautern-Landau, Erwin-Schrödinger Str. 46, 67663 Kaiserslautern, Germany

Topology is an important paradigm for our understanding of phases of matter in condensed matter, cold atoms and photonic systems. Here we present a new approach to realize topological states, which result from coupling the system to an environment. In a proof-of-principle study, we first eperimentally demonstrate open-system topological states using a plasmon-polariton waveguide plattform. The underlying, *a priori* topologically trivial lattice consists of a unit cell of four lattice sites which is equipped with spatially varied losses leading to a topological band structure. By tuning the hopping and the dissipation in the waveguide system, we observe both the emergence and the breakdown of a localized topological edge state. Moreoever, we present ongoing work, in which we develop an experimental platform to study non-Hermitian topological states in lattices of photon Bose-Einstein condensates within a dye-filled optical microcavity. The coupling to the reservoir of dye molecules here allows for gain, thermalization and tunable coherence properties of the photons, opening new pathways for the exploration of topological states in open systems.

Q 24.5 Tue 17:00 KG I Foyer

Collective oscillation modes of dipolar quantum droplets — •Denis Mujo and Antun Balaž — Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia

Since the first experimental realization of quantum droplets in dipolar Bose systems [1], it was shown [2] that they are stabilized against the collapse due to quantum fluctuations that correspond to the shift of the chemical potential [3]. We examine the behavior of collective oscillation modes of self-bound dipolar quantum droplets using a variational and numerical approach. We focus on cylindrically symmetric states and variationally derive frequencies and eigenvectors of low-lying collective modes, i.e., the breathing and the quadrupole mode. The obtained results are compared to full 3D numerical simulations based on the extended Gross-Pitaevskii equation, which includes both the quantum fluctuation and condensate depletion terms.

[1] H. Kadau et al., Nature **530**, 194 (2016).
[2] I. Ferrier-Barbut et al., Phys. Rev. Lett. **116**, 215301 (2016).
[3] A. R. P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011); Phys. Rev. A **86**, 063609 (2012).

Q 24.6 Tue 17:00 KG I Foyer

String Theory Applied: The Holographic Superfluid in One Spatial Dimension — •Florian Schmitt[1], Gregor Bals[2], Andreas Samberg[2,3], Carlo Ewerz[2,3], and Thomas Gasenzer[2,1] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [3]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt

This contribution is concerned with the investigation of non-equilibrium dynamics of superfluids in one spatial dimension enabled by the holographic description in terms of field theory in higher-dimensional black-hole-anti-de-Sitter spacetimes. We perform numerical solutions, applying the famous AdS/CFT duality of string and large-N field theory in a bottom-up fashion. Following the principles of holography this leads us to a way of calculating dynamics matched to the standard Gross-Pitaevskii-equation (GPE) based methods. The one-dimensional holographic superfluid is of peculiar fashion due to the renormalization needed on the boundary, which is due to the Weyl anomaly on the boundary not only consisting of the expected central charge. Of particular interest to us are topological defects, therefore we imprint solutions to the GPE, such as solitons, onto the superfluid and investigate how they evolve.

Q 24.7 Tue 17:00 KG I Foyer

Ultracold Quantum Gases in Spatially and Temporally Engineered Environments — •Erik Bernhart, Marvin Röhrle, Marco Decker, Jian Jiang, and Herwig Ott — Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Ultracold quantum gas experiments combined with high resolution and highly controllable optical techniques offer a unique platform to study quantum phenomena in driven quantum systems. Here, we report on the experimental realization of a Kapitza trap for ultracold 87Rb atoms, where the dynamical stabilization of the atomic motion by a time periodically modulated potential is demonstrated. While the time average of the potential vanishes, the corresponding Floquet-Hamiltonian results in a non-trivial effective time independent potential, which acts as a trap for the atoms.

To continue the investigations on driven systems and extend them to transport processes in time modulated optical potentials, we have upgraded our setup, which now combines a scanning electron microscope and a high resolution optical objective, through which we can imprint arbitrary repulsive potential landscapes, generated by an AOD. We have implemented a weakly coupled bosonic Josephson junction, with tunable and movable tunneling barrier and benchmark our system by observing the DC Josephson effect.

Q 24.8 Tue 17:00 KG I Foyer

Anomalous non-thermal fixed point in a quasi-2d dipolar Bose gas — •Niklas Rasch[1], Santo Maria Roccuzzo[1,2], Wyatt Kirkby[1,2], Lauriane Chomaz[2], and Thomas Gasenzer[1,3] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227 — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226 — [3]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16

In this work we focus on anomalous non-thermal fixed-points in the temporal evolution of a 2d dipolar Bose gas, exhibiting slow, subdiffusive coarsening characterized by algebraic growth of a characteristic length scale $L(t) \sim t^\beta$ with $\beta \ll 1/2$. Starting from variously sampled vortices on a uniform background, we evolve the Bose gas using the semi-classical truncated-Wigner approach. In the classical regime we reproduce the anomalous scaling exponent $\beta \simeq 1/5$ known from the single-component Bose gas with contact interactions, for various dipolar strengths and tilting angles. In the quantum regime we also recover such anomalously slow, subdiffusive scaling but find a dependence on the tilting angle, which leads to different scaling exponents and less stable scaling regimes. Within a quasi-2d setting, we analyze the dependence of the observed scaling exponents on the effects of anisotropy and on the long-range nature of the dipolar interaction. Anisotropy in the vortex configuration emerges; however, it is not reflected in the self-similar scaling. We focus on the role of vortex (anti-)clustering and observe regimes of strong clustering without correlation with the emergence of anomalously slow scaling.

Q 24.9 Tue 17:00 KG I Foyer

A new dysprosium quantum gas experiment — •Lucas Lavoine[1], Jens Hertkorn[1], Paul Uerlings[1], Kevin Ng[1], Fiona Hellstern[1], Tim Langen[1,2], Ralf Klemt[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart — [2]Atominstitut, TU Wien

Dysprosium offers the possibility to study degenerate quantum gases with anisotropic and long-range dipolar interactions competing with contact interactions. Tuning the relative interaction strength has led to the observation of new many-body states, including droplets and supersolids. While most of the experiment have been done in one-dimensional traps, recent theoretical works predict an exotic phase diagram in two-dimensional traps (2D), including honeycomb, labyrinthine, supersolid phases. The labyrinthine patterns are characterized by amorphous spatial structures consisting of elongated and bent density stripes and support superfluid flows along the stripes. We have recently built up a new dysprosium machine. With our new setup, we produce large Bose-Einstein condensates (BEC) with faster cycle times. By means of a high-NA (0.5) objective and a phase-contrast imaging technique, we are able to resolve spatial structures of about 0.5 micrometers. We plan to load the BEC in tailored potentials made by a digital micro-mirror device (DMD) with the aim to explore both the phase diagram of a 2D dipolar quantum gas and study the superfluid properties of the supersolid states by means of persistent currents in rotating ring-shaped potentials. On this poster we present the new experimental setup and report our recent experimental achievements.

Q 24.10 Tue 17:00 KG I Foyer

Resummations of the two-particle irreducible quantum effective action — •Hannes Köper[1] and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg

The two-particle irreducible quantum effective action can be formulated in terms of the Luttinger-Ward functional, which is diagrammatically given by the series of all two-particle irreducible vacuum Feynman diagrams. In this work, we reformulate infinite series of vacuum Feynman diagrams for scalar quantum field theories, whose potentials admit discrete frequency spectra such as the sine-Gordon model, in terms of spin systems on graphs. While the frequencies of the potential directly correspond to the possible spin values, the graph's topology is tightly connected to the class of vacuum diagrams that is being summed over. Different graph topologies thus correspond to different selective resummations of diagrams. In particular, cycle graphs correspond to "ring"-type resummations often encountered in next-to-leading order in $1/N$ expansions. This allows us to compute a closed form expression for the Luttinger-Ward functional within "ring-approximation" in terms of the eigenvalues of an associated transfer operator. We also present how the formalism may be applied to polynomial and $O(N)$-symmetric potentials.

Q 24.11 Tue 17:00 KG I Foyer

Optical quantum gases in box and ring potentials — •Patrick Gertz, Leon Espert Miranda, Andreas Redmann, Kirankumar Karkihalli Umesh, Frank Vewinger, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Quantum gases provide exquisite experimental control over dimensionality, shape of the energy landscape or the coupling to reservoirs, which opens the door to investigate novel states of matter both in and out of equilibrium. Here we report on the experimental realization of a quantum gas of photons inside box and ring-shaped potentials within a dye-filled optical microcavity. The trapping potential for the particles is provided by imprinting static nanostructures on the cavity mirror surface using a laser-induced delamination of the mirror coating. In a corresponding box-shaped cavity geometry, we have realized a 2D optical quantum gas at room temperature with uniform density and measured its compressibility and equation of state. In more recent work, we have achieved the quasi-1D, periodically closed confinement of photon gases in ring potentials. Prospects of this work include studies of the Kibble-Zurek mechanism and of flux qubits.

Q 24.12 Tue 17:00 KG I Foyer

Low-Energy Effective Field Theory for a Spin-1 BEC Far From Equilibrium — •Anna-Maria Elisabeth Glück, Ido Siovitz, Hannes Köper, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

The spin-1 Bose gas quenched far from equilibrium displays remarkable universal spatio-temporal self-similar scaling, which we hypothesize to be due to the system's vicinity to a non-thermal fixed point during its evolution back to equilibrium. This study introduces a low-energy effective field theory for the description of the phase-excitation dynamics in a one-dimensional spin-1 Bose gas following a quench from the polar to the easy-plane phase. In particular, we explore the incorporation of density fluctuations beyond the 1-loop order. Through numerical simulations, we subsequently compare the far-from-equilibrium scaling behavior of the effective theory to that of the fundamental theory.

Q 24.13 Tue 17:00 KG I Foyer

Pattern formation in dipolar quantum gases — •Andreea-Maria Oros[1], Niklas Rasch[1], Wyatt Kirkby[1,2], Lauriane Chomaz[2], and Thomas Gasenzer[1,3] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227 — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226 — [3]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16

Ultracold dipolar gases have garnered increasing interest over the past years. The anisotropic and long-range character of the dipolar interaction and the stabilizing nature of LHY corrections give rise to supersolidity, superglasses, and exotic states of matter. Different supersolid ground states, such as triangular, honeycomb, or even labyrinthine ones, were already theoretically predicted, depending on the atom number, scattering length, and trapping frequency. Our work expands on these phases by considering the out-of-equilibrium dynamics of a harmonically trapped, three-dimensional dipolar condensate. Following a quench in the scattering length across a phase transition boundary, we investigate the dynamical formation of supersolids, including those exhibiting novel crystalline structures. We further search for far-from-equilibrium phenomena, e.g., non-thermal fixed points, self-similar scaling, and the spontaneous formation of vortices in the pattern-forming regime. At the moment, quenches into the triangular and stripe phases have proven to be successful and promise insights into new physics, where time oscillations akin to a quadrupole mode of the droplets have been observed.

Q 24.14 Tue 17:00 KG I Foyer

Dynamical phases emerging from light-mediated interaction — •Anton Bölian[1], Phatthamon Kongkhambut[1], Jim Skulte[1], Ludwig Mathey[1], Jayson G. Cosme[3], Hans Kessler[2], and Andreas Hemmerich[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Quantenphysik, Universität Hamburg, Germany. — [2]Physikalisches Institut der Universität Bonn, Germany. — [3]National Institute of Physics, University of the Philippines, Diliman, Quezon City, Philippines.

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the very small field decay rate ($\kappa/2\pi = 3.5$ kHz), which is in the order of the recoil frequency ($\omega_{rec}/2\pi = 3.6$ kHz). This leads to a unique situation of a recoil-resolved cavity. Pumping the system with a steady state light field, red detuned with respect to the atomic resonance, the Dicke model is implemented including the self-organisation phase transition. Starting in the self-ordered superradiant phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetry-broken states. Modulation of the phase of the pump field gives rise to an incommensurate time crystalline behaviour. For a blue-detuned pump light with respect to the atomic resonance, we observe limit cycles (LCs). Since the pump protocol is time-independent, the emergence of LCs demonstrates the breaking of continuous time-translation symmetry.

Q 24.15 Tue 17:00 KG I Foyer

A Digital Micromirror Device setup and feedback algorithm for enhanced control of two-dimensional potentials in cold atoms experiments — •Marcel Kern, Marius Sparn, Nikolas Liebster, Elinor Kath, Jelte Duchêne, Helmut Strobel, and Markus Oberthaler — Kirchhoff-Institut für Physik, Heidelberg, Deutschland

Spatial light modulators are widely used in ultracold atom experiments to produce arbitrary optical traps. A seemingly simple, but important example is the box potential. Also, for dynamic processes, such as the injection of vortices, more complicated, time-dependent potentials are needed. However, imperfections in the incident light and projection system perturbs the expected potential, requiring finer control of the light potential along with active correction.

In our two-dimensional Bose-Einstein condensate (BEC) experiment of 39-K atoms, a Digital Micromirror Device (DMD) illuminated with off-resonant light is used to configure the in-plane potential. A second DMD that uses near-resonant light will allow manipulations on different energy scales to optimize the existing potential and manipulate the BEC locally. Additionally, feedback algorithms optimizing on light and atom distributions will further increase the quality of the created light potentials. We present the planning and characterization of a second DMD setup, as well as the optimization algorithms developed for our experiment.

Q 24.16 Tue 17:00 KG I Foyer

Time evolution in the Bose-Hubbard model using Matrix Product States — •Óscar Dueñas Sánchez[1] and Alberto Rodríguez[1,2] — [1]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain — [2]Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, E-37008 Salamanca, Spain

The dynamical evolution of out of equilibrium configurations in the Bose-Hubbard model is studied using Matrix Product States and Time-Evolving Block Decimation (TEBD). The goodness of the method is benchmarked against the exact dynamics implemented via an expansion of the time-evolution operator using Chebyshev polynomials for 'small' systems. We determine the optimal truncation value of the onsite modes' occupation number as a function of the interaction strength in order to capture faithfully the short time evolution across the chaotic phase using TEBD. Considering systems at unit density, sizes $L \gtrsim 40$, and times $t \lesssim 3$ (tunneling times) we analyse the fingerprint of the emergence of the chaotic phase from the potentially diffusive spreading of density-density correlations at early times.

Q 24.17 Tue 17:00 KG I Foyer

A new experimental platform to explore dipolar quantum phenomena in ultracold gases of magnetic atoms — Shuwei Jin, Jianshun Gao, Karthik Chandrashekara, Christian Gölzhäuser, Sarah Philips, Joschka Schöner, and •Lauriane Chomaz — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226

Ultracold quantum gases of highly magnetic atoms, such as dysprosium (Dy), have opened new avenues for the study of quantum phenomena. In particular, they bring into play the competition of anisotropic long-range dipole-dipole interactions, tunable short-range contact interactions, geometry, mean-field and beyond-mean-field effects. Mastering these competitions has led to the discovery of novel many-body quantum states in recent years, including liquid-like droplets, droplet crystals, and supersolids.

With my new group at the University of Heidelberg, we have designed and implemented a novel compact setup in which we have successfully produced large quantum degenerate gases of bosonic Dy atoms, achieved fine control of the dipolar and contact interactions, and are currently mastering their imaging with submicron resolution. We plan to load these quantum degenerate gases into tailorable traps that cross from 3D to 2D and have versatile in-plane potentials. Here I will present the design and implementation of our novel experimental setup, report on our recent achievements, and discuss prospective investigations we plan to undertake both in and out of equilibrium.

Q 24.18 Tue 17:00 KG I Foyer

Curved and Expanding Spacetimes studied with a Quantum Field Simulator — Celia Viermann[1], Marius Sparn[1], Nikolas Liebster[1], Maurus Hans[1], •Elinor Kath[1], Álvaro Parra-López[3], Mireia Tolosa-Simeón[4], Natalia Sánchez-Kuntz[5], Tobias Haas[6], Christian Schmidt[2], Helmut Strobel[1], Stefan Floerchinger[2], and Markus K. Oberthaler[1] — [1]KIP, Uni Heidelberg, Germany — [2]ITP, Uni Jena, Germany — [3]DFT, Uni Madrid, Spain — [4]LTPIII, Ruhr-Uni Bochum, Germany — [5]ITP, Uni Heidelberg, Germany — [6]CQIC, Uni libre de Bruxelles, Belgium

In most cosmological models, a rapid expansion of space in the early history of our universe is responsible for the creation of first structures. As the description of the involved processes is a theoretical challenge, quantum field simulators have proven to be valuable tools that offer an experimental approach to complex dynamics. We present such an experimental platform, based on a two-dimensional BEC, in which the phononic field simulates the evolution of a free, massless, scalar field in an FLRW spacetime. Positive and negative spatial curvatures can be implemented through specific atomic density distributions and can be made visible by observing the propagation of wave packets. An expanding spacetime can be simulated by decreasing the interatomic interactions. These expansions give rise to phononic excitations in a process analogue to cosmological particle production. We show that a statistical analysis of the resulting density fluctuation allows to differentiate between different expansion histories, which can be understood by mapping the process onto a stationary Schrödinger equation.

Q 24.19 Tue 17:00 KG I Foyer

Spin- and momentum-correlated atom pairs mediated by photon exchange and seeded by vacuum fluctuations — •Rodrigo Rosa-Medina, Fabian Finger, Nicola Reiter, Jacob Fricke, Panagiotis Christodoulou, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Engineering pairs of massive particles that are simultaneously correlated in their external and internal degrees of freedom is a major challenge, yet essential for advancing fundamental tests of physics and quantum technologies. Experiments with ultracold atoms provide a versatile platform for manipulating and detecting such correlations at a microscopic level.

In our experiment, we couple a spinor Bose-Einstein condensate of Rb-87 atoms to a high-finesse optical cavity. By leveraging the strong light-matter interactions, we engineer correlated pairs of atoms both in their internal (spin) and external (momentum) degrees of freedom through the exchange of virtual cavity photons. The measured pair statistics are compatible with pair production being seeded by vacuum fluctuations in the corresponding atomic modes. We observe a collectively enhanced formation of atom pairs and demonstrate their correlated nature by probing momentum-space noise correlations. Furthermore, we optically control the interplay between unitary and competing dissipative processes, and observe coherent pair oscillations. Our findings provide prospects for quantum-enhanced matterwave interferometry and quantum simulation experiments with correlated atoms.

Q 24.20 Tue 17:00 KG I Foyer

Polarons and bi-polarons in strongly interacting 1D Bose gases — •Dennis Breu, Martin Will, and Michael Fleischhauer — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

We investigate the ground state, the dynamics and effective interactions of quantum impurities immersed in an interacting 1D Bose gas utilising Tensor Network simulations. The algorithm allows us to theoretically probe Bose polarons in the regime of strong interactions in the Bose gas for the full range of Tonks parameters γ. We calculate the polaron binding energy as well as Born-Oppenheimer polaron interaction potentials and bi-polaron bound states and compare them to analytical predictions in the weak and strong coupling regimes. Furthermore we investigate the dynamics of a single finite mass impurity inside a finite size 1D Bose gas. Here we find a crossover to a localised impurity at the edges of the system instead of one that is spread over the whole system. Finally by making use of time-evolving block decimation (TEBD) we study the dynamics of impurities accelerated by a constant force inside a strong interacting 1D Bose gas and find oscillations reminiscent of Bloch oscillations.

Q 24.21 Tue 17:00 KG I Foyer

Spinor Bose-Einstein condensate as Platform for Studying Extreme Wave Events — Yannick Deller, Ido Siovitz, •Alexander Schmutz, Felix Klein, Helmut Strobel, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff Institut for Physics, Ruprecht-Karls-University Heidelberg

Many-body systems far from equilibrium can exhibit self-similar dynamics characterized by universal exponents. Studies of the 1D spinor Bose gas have shown [1], that the value of these exponents is connected with the occurrence of extreme wave excitations in the mutually coupled magnetic components. Numerical simulations showed that real-time instanton defects appear as a result of the caustics, manifesting as spin-1 vortices in space-time. To characterize these experimentally, we employ local spin-dependent phase imprints. We investigate the resulting deterministic excitations and their connections to real-time instantons.

[1] Siovitz at. al., PRL 131, 183402 (2023)

Q 24.22 Tue 17:00 KG I Foyer

The Quantum Gas Magnifier as a Coherence Microscope — •Mathis Fischer, Justus Brüggenjürgen, and Christof Weitenberg — Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Imaging is crucial for gaining insight into physical systems. In the case of ultracold atoms in optical lattices, the novel technique of quantum gas magnification opens the way to explore 3D systems with large occupation numbers with sub-lattice site resolution.

We report on the realization of an all-optical quantum gas magnifier for ultracold Lithium-7 atoms. The all-optical approach allows us to address the broad Feshbach resonance of Lithium to control the interaction strength. With this technique, we directly image the Talbot carpet that forms when releasing the atoms from an optical lattice. After certain ballistic expansion times, the wave packets originating from each lattice site overlap and constructively interfere with each other, such that an image of the original density distribution is obtained. We map out the spatial coherence by analyzing the contrast of consecutive Talbot copies. The technique should also allow to reconstruct the fluctuating phase profile of individual samples imaged at a single Talbot copy. This will realize a coherence microscope with spatially resolved access to phase information allowing to study domain walls, thermally activated vortex pairs, or to locally evaluate coherence in inhomogeneous quantum many-body systems.

Q 24.23 Tue 17:00 KG I Foyer

The smallest possible heat engine — James Anglin and •Viviane Bauer — Landesforschungszentrum OPTIMAS, RPTU Kaiserslautern-Landau, Germany

Microscopic engines are a research focus in both biochemistry and nanotechnology. While other forms of engines besides heat engines are also being considered, the fully microscopic limit of a heat engine is a fundamentally important problem in physics. What happens to thermodynamics when not only the working fluid and mechanism of a heat engine are microscopic, but even the hot and cold reservoirs are? We have found a theoretical model for such fully microscopic heat engines in the form of two coupled three-mode Bose-Hubbard systems (two trimers). Such subsystems can equilibrate in chaotic ergodization. If coupled together they exhibit energy and particle transport: the processes, which heat engines exploit to perform work. We can also couple a weight to the Bose-Hubbard system, in a way which uses this transport to lift the weight. Moreover we have identified a dynamic mechanism which can stabilise this lifting process. The result is a system which operates just like a heat engine, except for being fully microscopic. The structure of coupled chaotic subsystems both supports and requires an understanding of the fully microscopic heat engine in terms of open-system control.

Q 24.24 Tue 17:00 KG I Foyer

Heidelberg Quantum Architecture: Highly controlled light potentials in a 2D Fermi gas — •Johanna Schulz, Juan Carlos Provencio Lameiras, Suraj Iyer, Tobias Hammel, Maximilian Kaiser, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut - Heidelberg University, Heidelberg, Germany

Heidelberg Quantum Architecture (HQA) is a new ^{6}Li quantum gas experiment providing a fast, versatile, and expandable experimental platform for programmable quantum simulation. In this poster we present two optical modules that allow for creating various potentials, an accordion lattice and a Digital Micromirror Device.

A lot of interesting physics arises in lower-dimensional systems and in the crossover between dimensions. Going to 2D can be conducted using an optical accordion that creates an interference pattern with tuneable lattice spacing between 1.2μm and 15μm. That way, we can create quickly varying potentials, allowing for optimized loading and wide control of the 2D system. This we realize in a highly compactified optical module increasing stability and enhancing maintainability.

To generate nicely controllable light potentials, one can use, among other devices, a digital micromirror device (DMD). We present an exceptionally compact setup to create arbitrary potentials. One physical system that we want to simulate is a box potential in a scale of up to 200μm and as small as 50μm to confine the atoms.

Q 24.25 Tue 17:00 KG I Foyer

Signatures of Anderson localization in a degenerate Fermi gas beyond exponential density distributions — •Sian Barbosa, Maximilian Kiefer-Emmanouilidis, Felix Lang, Jennifer Koch, and Artur Widera — Department of Physics and Research Center OPTIMAS, RPTU, Kaiserslautern, Germany

Disorder can fundamentally modify the transport properties of a system. A striking example is Anderson localization, suppressing transport due to destructive interference of propagation paths. Especially in inhomogeneous many-body systems, not all particles will localize for finite-strength disorder, and the system can become partially diffusive.

Even for extended, i.e. non-localized states, exponential tails can develop after purely diffusive transport and falsely simulate localization, especially when the diffusion coefficient becomes energy dependent. I will present the results of our experimental investigation of a degenerate, spin-polarized Fermi gas released into a disorder potential formed by an optical speckle pattern. Using standard observables, such as diffusion exponent and coefficient, localized fraction, or localization length, we find that some show signatures for a transition to localization above a critical disorder strength, while others show a smooth crossover to a modified diffusion regime. In laterally displaced disorder, we spatially resolve different transport regimes simultaneously which allows us to extract the subdiffusion exponent expected for weak localization. Our work suggests alternative measures to the misleading concept of exponential tails.

Q 24.26 Tue 17:00 KG I Foyer

Fermi accelerating an Anderson-localized Fermi gas to superdiffusion — Sian Barbosa, Maximilian Kiefer-Emmanouilidis, •Felix Lang, Jennifer Koch, and Artur Widera — Department of Physics and Research Center OPTIMAS, RPTU, 67663 Kaiserslautern, Germany

Disorder can have dramatic impact on the transport properties of quantum systems. Anderson localization, arising from destructive quantum interference of multiple scattering paths suppresses the transport entirely. Processes involving time-dependent random forces such as Fermi acceleration, proposed as a mechanism for high-energy cosmic particles, can expedite particle transport significantly. The competition of these two effects in time-dependent inhomogeneous or disordered potentials can give rise to fascinating dynamics. Experimental observations are paramount, although scarce. Here, I present our experimental study of the dynamics of an ultracold, non-interacting Fermi gas expanding inside a disorder potential with finite spatial and temporal correlations. Depending on the disorder's strength and rate of change, we observe several distinct regimes of tunable anomalous diffusion, ranging from weak localization and subdiffusion to superdiffusion. Especially for strong disorder, where the expansion reveals effects of localization, an intermediate regime is present in which quantum interference appears to counteract acceleration. Our system connects the phenomena of Anderson localization with second-order Fermi acceleration and paves the way toward experimentally investigating Fermi acceleration when entering the regime of quantum transport.

Q 24.27 Tue 17:00 KG I Foyer

Rapid Fermionic Quantum Simulation for Random Unitary Observables — •Marcus Culemann[1,2], Daniel Dux[1], Xinyi Huang[1,2], Jonas Kruip[1,3], Naman Jain[1], Jin Zhang[1], and Philipp Preiss[1,4] — [1]Max Planck Institute of Quantum Optics, Garching — [2]Ludwig-Maximilians-Universität, Munich — [3]ETH Zurich — [4]Munich Center for Quantum Science and Technology

Ultracold atoms in optical lattices provide an experimental platform to perform controlled single-particle operations in many-body systems. The UniRand experiment aims to leverage this control to study physics at the interface between condensed matter physics and quantum information science. One exciting avenue towards this goal are measurements in random bases using so-called random unitary protocols. They are predicted to give access to global density matrix properties and provide a general way of characterizing many-body systems in and out of equilibrium. We report on the progress of building a fermionic quantum simulator capable of realizing random unitaries with high repetition rates and a high-fidelity readout process. At present, the experiment demonstrates the use of 2D-MOT as a cold atom source, capable of loading with high rates into the 3D-MOT, and atom counting capability with single atom resolution. The envisaged system combines evaporative cooling in optical tweezer arrays followed by quantum state assembly in a tunable optical lattice. The readout process aims to reach single site resolution by using matter wave magnification and spin-resolved free-space imaging. The poster will summarize the current status and future prospects of the experiment.

Q 24.28 Tue 17:00 KG I Foyer

Identification of Quantum Phases with Unsupervised Machine Learning — •Niklas Käming[1,3], Paolo Stornati[2], Klaus Sengstock[1,3,4], and Christof Weitenberg[1,3,4] — [1]IQP - Institut für Quantenphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]ICFO - Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [4]ZOQ - Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Machine learning techniques are a versatile tool to identify many-body quantum states without knowledge of the order parameters. Using such techniques to identify phases of matter has gained high popularity in many-body physics and the cold quantum gas community. In this poster, we present unsupervised machine-learning techniques that have been proven to be universally successful in mapping out the extended Fermi-Hubbard model from simulated entanglement spectra and the Haldane model from experimental cold quantum gas data. In the future, we hope to find new phases of matter by performing experiments in theoretical non-tractable regimes.

Q 24.29 Tue 17:00 KG I Foyer

Report on an Erbium-Lithium machine — •Florian Kiesel, Alexandre De Martino, Kirill Karpov, Jonas Auch, and Christian Gross — Eberhard Karls Universität Tübingen, Physikalisches Institut, Auf der Morgenstelle 14, 72076 Tübingen

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

Q 24.30 Tue 17:00 KG I Foyer

Heidelberg Quantum Architecture: Fast spin manipulation and magnetic field stabilization in a Fermi gas — Johanna Schulz, •Suraj Iyer, Juan Carlos Provencio Lameiras, Tobias Hammel, Maximilian Kaiser, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut - Heidelberg University, Heidelberg, Germany

Heidelberg Quantum Architecture (HQA) is a new ^{6}Li quantum gas experiment providing a fast, versatile, and expandable experimental platform for programmable quantum simulation. This poster presents techniques for spin manipulation and stabilization of magnetic fields generated by our Feshbach coils.

To prepare a deterministically controlled mixture of spin states, we drive Rabi oscillations between hyperfine states of the $2S_{1/2}$ ground state. We build radiofrequency and microwave coils that are mounted outside the science glass cell, to keep the components exchangeable, hence providing high magnetic fields at the position of the atoms. We are aiming for magnetic fields and Rabi oscillations in the order of 100kHz, which is about ten times faster than other machines in our group.

In the HQA high-fidelity control of interactions is realized by stabilizing the magnetic bias fields generated by the Feshbach coils. Fluctuations are mitigated by using a PID loop which measures the coil current through current transducers (CT). By using multiple CTs, we can achieve precise tunability of individual field parameters which includes the field offset, the field gradient, and the field curvature.

Q 24.31 Tue 17:00 KG I Foyer

Kapitza-Dirac scattering of strongly interacting Fermi gases — •Max Hachmann[1], Yann Kiefer[1,2], and Andreas Hemmerich[1] — [1]Universität Hamburg, Hamburg, Deutschland — [2]ETH, Zürich, Schweiz

We experimentally probe properties of interacting spin-mixtures of fermionic (40K) atoms by studying their interaction with light. An elementary scattering scenario is resonant Bragg diffraction, also referred to as Bragg spectroscopy, where matter is diffracted from a onedimensional (1D) optical standing wave. A Feshbach resonance is used to tune the interactions across the entire BEC-BCS crossover regime, including the point of unitarity. With the preparation schemes available in our experiment, the scattering lengths can be dynamically tuned, such that either repulsively bound molecular dimers (Feshbach molecules) or pairs of unbound fermions can be studied. To benchmark our scattering protocol, we apply it to a sample of spin-polarized non-interacting fermionic atoms and study the dynamical behaviour. In this case, a simple model using a time-dependent Schrödinger equation yields surprisingly accurate results, well matching the experimental observations. For spin-mixtures in the unitarity regime, the higher order diffraction peaks are observed to disappear with no conclusive theoretical description presently available.

Q 24.32 Tue 17:00 KG I Foyer

Observation of hydrodynamics and pairing in a few-fermion system — •Sandra Brandstetter, Carl Heintze, Karen Wadenpfuhl, Philipp Lunt, Keerthan Subramanian, Marvin Holten, Maciej Galka, and Selim Jochim — Universität Heidelberg, Heidelberg, Germany

Fermionic quantum systems, adjustable in atom numbers, are our tool to explore emergent many-body phenomena. Our experimental setup allows the deterministic preparation of 6Li atoms in the ground state of a two-dimensional harmonic potential.

We use matter wave magnification techniques to measure individual atoms' positions or momenta. Previous experiments unveiled phase transitions [1] and Cooper pairs [2].

In our experiments we observe elliptic flow in systems as small as 10 particles, challenging the traditional understanding of hydrodynamics [3]. Presently, we're focused on exploring the transition from a two-particle bound state to the many-body Cooper pairs using our ability to access real space correlations.

Future objectives include extracting the contact parameter, studying open shell configurations akin to nuclear physics, and observing interference among identical few-body systems.

[1]Bayha et al. Nature 587 (2020)
[2]Holten et al. Nature 606 (2022)
[3]Brandstetter et al. arXiv: 2308.09699v1 (2023)

Q 24.33 Tue 17:00 KG I Foyer

Heidelberg Quantum Architecture: Fast and modular programmable quantum simulation — •Maximilian Kaiser[1], Tobias Hammel[1], Philipp Preiss[2], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut - Heidelberg University, Heidelberg, Germany — [2]Max Planck Institute of Quantum Optics, Garching, Germany

Heidelberg Quantum Architecture (HQA) is a new ^{6}Li quantum gas experiment providing a fast, versatile, and expandable platform for programmable quantum simulation. In this poster, we give an overview of its design and its inherent modular structure which can be easily adapted to the needs of most of today's quantum gas experiments.

We present the interface concept of our machine alongside the capabilities of our current experimental toolbox, implemented as exchangeable modules. These include among others tunable 2D confinements, arbitrarily shaped potential landscapes, single-atom counting capabilities, and spin-resolved-imaging. Enabled by this toolbox, we report on the latest research results such as the sub-second production of a degenerate fermi gas of ^{6}Li atoms.

Q 24.34 Tue 17:00 KG I Foyer

Quantized pumping in optical lattices: interactions and edge modes — •Giacomo Bisson, Zijie Zhu, Konrad Viebahn, Samuel Jele, Marius Gächter, Anne-Sophie Walter, Joaquin Minguzzi, Stephan Roschinski, Kilian Sandholzer, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich

Understanding the underlying geometric properties of wave functions in topological quantum systems is essential in explaining phenomena such as the quantized Hall effect and Thouless pumps. However, interparticle interactions can affect the topology of a system. In our work, we study topological Thouless pumps via an experimental realization using optical lattices where the Hubbard interaction can be tuned. We observe regimes with robust pumping, as well as an interaction-induced breakdown. The pump shows robustness against weak interactions, both repulsive and attractive. Strongly attractive interactions enable quantized transport through the formation of fermion pairs. Conversely, strong repulsive interaction impairs topological pumping, necessitating pump trajectory modifications to restore it. Furthermore, we explore pump trajectories that are trivial in the non-interacting case and non-trivial in the interacting case resulting in an interaction-induced charge pump. Additionally, we study the transport properties of gapless edge modes in a harmonically confined topological pump. When ultracold fermionic atoms reach a critical slope of the confining potential, quantized Hall drifts reverse, indicating a topological boundary. This reversal corresponds to a band transfer between bands with Chern numbers C = +1 and C = -1 through a gapless edge mode.

Q 24.35 Tue 17:00 KG I Foyer

Towards quantum gas microscopy with dynamically projected optical lattices — •Samuel Jele, Marius Gächter, Giacomo Bisson, Zijie Zhu, Tilman Esslinger, and Konrad Viebahn — Institute for Quantum Electronics, ETH Zurich

In this poster, a novel design for a quantum gas microscope of fermionic potassium (K40) will be presented. In addition to a high-NA objective, the key idea behind achieving single-site resolution makes use of two superimposed accordion lattices with variable and independent lattice constants [1]. By handing over atoms on individual sites from one accordion lattice to the other during lattice expansion, an, in principle, arbitrarily large atom spacing can be achieved, giving access to single-site-resolution with very low imaging duration and lattice depth. Besides single-site resolution, the setup is designed for a repetition rate of 1Hz. For this we implement a parallelisation scheme for laser cooling, evaporative cooling, as well as physics measurements of multiple runs. In addition, a steep magnetic gradient ($>$ 1000G/cm) for rapid evaporative cooling, two separate 3D MOT chambers for potassium and rubidium and fast transport to the glasscell using a moving lattice will help us achieve this goal. The implementation of the accordion lattice using acousto-optic deflectors will allow us to project various lattice structures by simply changing the RF driving signal. This enables us to study more complex systems, such as the Lieb lattices, quasi-periodic structures as well as novel Floquet driving schemes.

[1]: Simon Wili et al., New J. Phys. 25 033037 (2023)

Q 24.36 Tue 17:00 KG I Foyer

Prospects for experiments with ultracold atoms in a five-fold symmetric quasicrystal optical lattice with tunable geometrie — •Jonathan Bracker[1], Luca Asteria[1,2], Marcel Nathanael Kosch[1], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany

Quasicrystal lattices constitute a fascinating middleground between periodic lattices and disordered systems with intricate topological properties and exotic many-body phases. They can be considered as a projection from a higher dimensional space, from which they inherit their topology. First experiments with ultracold atoms in quasiperiodic lattices have been realized in recent years, but so far, the higher dimensional space had a trivial geometry. Here we present a way to realize a quasicrystal lattice with a non-trivial underlying geometry. This setup is characterized by a five-fold rotational symmetry and we discuss how it will be realized via a multi-frequency scheme with full dynamical control over the geometric degree of freedom [1]. We also present numerical results on the expected transport and localization properties as a function of this geometric degree of freedom.

[1] M. Kosch et al., Phys. Rev. Research 4, 043083 (2022)

Q 24.37 Tue 17:00 KG I Foyer

Linear Prediction Algorithms to enhance Impurity Solvers for Dynamical Mean Field Theory — •Bastian Schindler — Goethe-Universität, Institut für Theoretische Physik, 60438 Frankfurt am Main, Germany — Arnold-Sommerfeld-Zentrum für Theoretische Physik, LMU München, Theresienstr. 37, 80333 München

In the poster based on my bachelors thesis an empirical study of different linear prediction algorithms (Yule-Walker, Burg, covariance, modified covariance) using various implementations in python is presented. These algorithms are based on an autoregressive process and are being tested on the Greens functions generated during four different dynamical mean field theory (DMFT) simulations. To evaluate real world performance the root mean squared error is computed on a test sample, which was excluded from the previous fitting process. The dependency of this error with respect to most of the important hyperparameters is analysed systematically. Spectrums implementation of the covariance method is found to perform superiorly on weakly oscillating functions, whereas the Burg method from the same package overall performs better on strongly oscillating functions. The discarded weight is found to be a good parameter to distinguish between the two cases. A Nelder-Mead optimization scheme to find the relevant hyperparameters is successfully implemented. As my current interest in my masters project (Bose-Hubbard model with disorder) revolves heavily around bosonic DMFT, the link to (B)DMFT will be emphasized more than in the original thesis.

Q 24.38 Tue 17:00 KG I Foyer

Cooperative effects in dense cold atomic gases including magnetic dipole interactions — •Nico Bassler[1,2], Ishan Varma[3], Marvin Proske[3], Patrick Windpassinger[3], Kai Phillip Schmidt[1], and Claudiu Genes[2,1] — [1]Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany — [3]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55122 Mainz, Germany

We theoretically investigate cooperative effects in cold atomic gases exhibiting both electric and magnetic dipole-dipole interactions, such as occurring for example in clouds of dysprosium atoms. We distinguish between the quantum degenerate case, where we take a many-body physics approach, and the quantum non-degenerate case, where we use the formalism of open system dynamics. For quantum non-degenerate gases, we illustrate the emergence of tailorable spin models in the high-excitation limit. In the low-excitation limit, we provide analytical and numerical results detailing the effect of magnetic interactions on the directionality of scattered light and characterize sub- and superradiant effects. For quantum degenerate gases, we study the interplay between sub- and superradiance effects and the fermionic or bosonic quantum statistics nature of the ensemble.

Q 24.39 Tue 17:00 KG I Foyer

Photon Storage using Cold Caesium in an Interrupted Waveguide — •Matt Overton, David Johnson, Danielle Baldolini, Nathan Cooper, and Lucia Hackermuller — School of Physics and Astronomy, University of Nottingham, UK

Cold atoms are useful for many quantum information applications. Their strong interactions with light give them many uses in atom-photon junctions. However, one difficulty with cold atoms is integrating them with waveguides and other photonic devices. Here we demonstrate a method that involves trapping the atoms inside a micromachined hole through an optical fibre. By carefully selecting the geometry of the cavity, one can tune the transmission of light through it, with convex parabolic surfaces having the greatest transmission [1].

Here we use caesium atoms to demonstrate electromagnetically induced transparency (EIT) within the waveguide hole. EIT allows the transparency of a medium to be controlled using a laser field. The effects this has on the complex susceptibility leads to slow light and (if the control laser power is reduced to zero) can also lead to photon storage. Integrating cold atoms into an optical waveguide for storage like this has obvious applications in quantum computing and quantum communication.

[1] Cooper, N., Da Ros, E., Briddon, C. et al. Prospects for strongly coupled atomphoton quantum nodes. Sci Rep 9, 7798 (2019)

Q 24.40 Tue 17:00 KG I Foyer

Quantum gas mixtures in an Earth-orbiting research laboratory — •Annie Pichery[1,2], Timothé Estrampes[1,2], Gabriel Müller[1], Nicholas P. Bigelow[3], Eric Charron[2], Naceur Gaaloul[1], and the CUAS Consortium[3] — [1]Leibniz Universität Hannover,Institut für Quantenoptik, Germany — [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France — [3]University of Rochester, Rochester, NY, USA

The Cold Atom Laboratory (CAL) is a multi-user Bose-Einstein Condensate (BEC) machine aboard the International Space Station, operated by NASA's Jet Propultion Lab. Since its upgrade in 2020, it enables the production and manipulation of dual-species BEC mixtures of K and Rb. We report here about the first quantum mixture experiments realized in space [E. Elliott et al., Nature 623, 502 (2023)] and study its dynamics in weightlessness to prepare dual-species atom interferometry and future tests of the Universality of Free Fall.

Space provides, indeed, an environment where atom clouds can float for extended times of several seconds, as well as miscibility conditions different from ground. Simulating these quantum phases and the dynamics of interacting dual species presents however computational challenges due to the long expansion times. We present a novel theoretical framework based on re-scaled computation grids that allowed to follow the extended free dynamics of quantum mixtures in space.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under Grant No. CAL-II 50WM2245A/B.

Q 24.41 Tue 17:00 KG I Foyer

Rydberg superatoms for waveguide QED — •Daniil Svirskiy, Lukas Ahlheit, Christoph Biesek, Jan de Haan, Nina Stiesdal, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Waveguide-systems where quantum emitters are strongly coupled to a single propagating light mode offer an interesting platform for quantum nonlinear optics. We work towards realizing a cascaded waveguide system utilizing Rydberg superatoms - single Rydberg excitations in individual atomic ensembles smaller than the Rydberg blockade-volume - as effective, directional two-level emitters. Due to the collective nature of the excitation, the superatom effectively represents a single emitter, that is coupled to the inicdent single photon light. The directional emission of the superatom into the initial probe mode realizes a waveguide-like system in free space without any actual light-guiding elements.

On this poster, we show how a Rydberg superatom allows manipulation of single photons, and demonstrate how we implement a one-dimensional chain of Rydberg superatoms with low internal dephasing. To increase coherence time, we use a magic wavelength optical lattice that traps atoms in both the ground- and the Rydberg state and thus reduce atomic motion and limit dephasing of the collective excitation.

We further show how we use an interferometer setup to perform quantum state tomography on multi-photon pulses passing through the superatoms in order to characterize the effective photon-photon interaction mediated by the superatom chain.

Q 24.42 Tue 17:00 KG I Foyer

Interfacing electromechanical oscillators and Rydberg atoms in a closed-cycle cryostat — •Leon Sadowski, Cedric Wind, Johanna Popp, Julia Gamper, Valerie Mauth, Wolfgang Alt, Hannes Busche, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Rydberg atoms exhibit strong electric dipole transitions between Rydberg states, which allow coupling to other quantum systems at microwave frequencies. Here, we present the prospect to couple Rydberg atoms to electromechanical oscillators, which can possess high Q factors at microwave frequencies, and our implementation of a cryogenic cold atom setup for such experiments.

On this poster, we present our progress on the construction of the experimental setup that is centered around an UHV closed-cycle cryostat that allows to perform experiments in a 4 K environment and includes a vibration-isolation system that reduces vibrations below 25 nm. Moreover, we show our design of a chip on which we integrate the oscillator and a superconducting wire trap that allows for magnetic trapping of Rubidium atoms above the oscillator at distances of several 10 μm. For the oscillator, we perform finite element simulations of the field radiated due to thermal phonons and deduce interaction strengths with Rydberg atoms of order kHz to MHz if the oscillator is near its quantum ground state.

In summary, the 4 K environment combined with dissipative interactions with Rydberg atoms should enable cooling the oscillator to its ground state without the need of a dilution refrigerator.

Q 24.43 Tue 17:00 KG I Foyer

Rydberg superatoms coupled with super-extended evanescent field nanofiber at the single-photon level — •Tangi Legrand[1], Ludwig Müller[1], Thomas Hoinkes[2], Xin Wang[1], Thilina Muthu-Arachchige[1], Eduardo Uruñuela[1], Wolfgang Alt[1], and Sebastian Hofferberth[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Department of Physics, Humboldt University of Berlin, Germany

Both Rydberg superatoms driven by free-space photonic modes and single emitters coupled to photonic waveguides have paved the way for strong coherent light-matter coupling at the few-photon level. By combining advantages of both ideas, we aim to achieve homogeneous coupling of multiple Rydberg superatoms coupled to a field thighly confined by a nanofiber. Fibers with diameters of a few hundred nanometers are successfully used to trap and couple arrays of single atoms by their evanescent field. Recent advances allow the fibers to be tapered to even smaller diameters, allowing more than 99 % of the energy to be guided outside the fiber with effective field diameters of $\gtrsim 13\,\lambda$ [1], bringing them up to typical Rydberg blockade radius sizes.

On this poster, we present our strategy for building an apparatus that allows multiple Rydberg superatoms to be trapped around a nanofiber with a diameter of about 100 nm. We select Ytterbium due to its advantage of having the two-photon Rydberg excitation transitions close together with 399 nm and 395 nm, which simplifies the fiber design and is expected to have low thermal dephasing effects.

[1] R. Finkelstein *et. al.* Optica **8**, 208-215 (2021)

Q 24.44 Tue 17:00 KG I Foyer

Rydberg quantum optics in ultracold Ytterbium gases — •Eduardo Uruñuela, Xin Wang, Thilina Muthu-arachchige, Tangi Legrand, Ludwig Müller, Wolfgang Alt, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons. Demonstrations of photon-photon gates or multi-photon bound states based on this concept have so far exclusively employed ultracold alkali atoms. Two-valence electron species, such as ytterbium, offer unique novel features such as narrow-linewidth laser-cooling, optical detection and ionization or long-lived nuclear-spin memory states.

In this poster, we present our experimental progress on the realization of strong interaction between photons, enabled by Yb-174 Rydberg polaritons formed in a 1-D ultracold Ytterbium gas. Owing to the zero nuclei spin of Yb-174 and singlet spin state in bivalent structure, the longer coherent time is expected. The singlet transition at 399 nm also helps us produce a long-focused dipole trap with higher OD in one dimension. Specifically, we discuss our implementation of ultracold Yb atoms in narrow-line MOT and elongated dipole trap with compact and fast-loading two-chamber experiment setup, and generation of the Rydberg polaritons under Rydberg electromagnetically induced transparency.

Q 24.45 Tue 17:00 KG I Foyer

Critical exponents of a non-equilibrium phase transition in a facilitated Rydberg gas — •Daniel Brady, Simon Ohler, and Michael Fleischhauer — RPTU Kaiserslautern

We study a gas of driven Rydberg atoms, where excitations can spread through facilitation, comparable to the spread of an infectious disease. Importantly, the system shows a non-equilibrium dynamical phase transition from an active to an absorbing state, depending on driving and density. This transition is characterized by two critical exponents, which we investigate numerically close to the critical point as a function of the gas temperature. For the case of very low temperatures, we find a directed percolation-type transition due to the effects of Rydberg blockade, whereas for increasing temperatures we find a crossover to a mean-field transition. We also study the fast *avalanches* of excitations at the critical point and find they are power-law distributed with an exponent that is independent of temperature and comparable to many other systems known under the term self-organized criticality.

Q 24.46 Tue 17:00 KG I Foyer

Experimental Setup for the Generation of Chiral Orbital States with Rydberg Atoms — •Peter Zahariev[1,3], Stefan Aull[1], Steffen Giesen[2], Robert Berger[2], and Kilian Singer[1] — [1]Experimentalphysik I - Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel — [2]Fb.15 - Chemie, HansMeerwein-Straße 4, 35032 Marburg — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

We present an experimental setup based on a magneto-optical trap of Rubidium atoms and two photon excitation into Rydberg states, that allows for the preparation of chiral orbital Rydberg states. Using hydrogen-like wave functions [1], it is possible to construct an electron density and probability current distribution that has chiral nature. The radio frequency setup and the electric field configuration to generate and detect these states is presented. This experiment will allow us to identify interaction induced energy shifts that are caused by the chiral nature of the wave function only. The results will be also valuable for chiral discrimination of molecules [2].

[1] A. Ordonez, O. Smirnova. Propensity rules in photoelectron circular dichroism in chiral molecules. I. Chiral hydrogen, Phys. Rev. A 99, 043416 (2019)

[2] S Y Buhmann *et al*, Quantum sensing protocol for motionally chiral Rydberg atoms, *New J. Phys.* **23** 083040 (2021)

Q 24.47 Tue 17:00 KG I Foyer

Rydberg spectroscopy in the strong driving regime and self-organized criticality — •Patrick Mischke[1,2], Florian Binoth[1], Jana Bender[1], Thomas Niederprüm[1], and Herwig Ott[1] — [1]Department of Physics and Research center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau — [2]Max Planck Graduate Center with the Johannes Gutenberg-Universitätt Mainz (MPGC)

Autler-Townes splitting in coupled two-level-systems is a well-known effect in atomic physics. However, for strong driving in real atomic systems, additional states like other hyperfine structure states or magnetic sublevels are admixed. As a result, complex spectra, deviating from the symmetrical two-level Autler-Townes splitting, emerge.

We experimentally investigate these spectra in a thermal cloud of ^{87}Rb atoms by resonantly coupling the $6P_{3/2}, F = 3$ state to a Rydberg state with varying Rabi frequency.

Our experiments confirm, that multilevel effects have to be considered in the Autler-Townes regime. As a general rule, the splitting between peaks is not equal to the Rabi frequency if the coupling strength exceeds the energetic distance of adjacent states.

In a manybody system, Rydberg atoms interact strongly over very large distances, leading to effects such as blockade and facilitation. In the absence of disorder, an off-resonantly driven system is expected to exhibit a phase transition between an active and an absorbing phase. We present experimental data and our work towards understanding the role of disorder.

Q 25: Precision Spectroscopy of Atoms and Ions II (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: HS 1098

Q 25.1 Wed 11:00 HS 1098

An ultra stable dc voltage source for ion trap experiments — •Dina-C. Rensink[1], Peter Micke[2,5], Markus Wiesinger[2], Christian Will[2], Hüseyin Yildiz[1], Christian Smorra[1,4], Jochen Walz[1,3], and Stefan Ulmer[6,4] — [1]Johannes Gutenberg-Universität Mainz — [2]Max-Planck-Institut für Kernphysik, Heidelberg — [3]Helmholtz-Institut Mainz — [4]RIKEN, Wako, Japan — [5]Helmholtz-Institut Jena — [6]Heinrich-Heine-Universität Düsseldorf

Highly stable voltages are crucial for precision ion traps. We are developing and characterizing a suitable voltage source for the BASE (Baryon-Antibaryon Symmetry Experiment) collaboration at CERN, which operates several Penning traps. These precision traps are used to perform test of the fundamental symmetry (CPT) between matter and antimatter with (anti-)protons, for instance via comparison of the g-factors. The determination of these quantities requires several frequency measurements whose precision can be limited by the stability of the voltages which bias the trap electrodes.

For this purpose, one ultra-stable LTZ1000 voltage reference and five 20 bit DACs have been combined into a programmable 5-channel voltage source. This scalable setup aims at long-term stability, low temperature drift, μV resolution over a ± 10 V range, and an output current of up to 20 mA per channel. Prior tests with a 2-channel prototype indicate a fractional stability of $< 5 \cdot 10^{-8}$ at $\tau = 10^2...10^3$ s (at 7 V). The status of the project will be presented and the performance of the voltage source will be discussed.

Q 25.2 Wed 11:15 HS 1098

Atomic level search in lawrencium — •Elisabeth Rickert for the Lawrencium-Collaboration — GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany — Johannes Gutenberg-Universität Mainz, 55128 Mainz,Germany — Helmholtz-Institut Mainz, 55128 Mainz, Germany

The study of the electronic shell structure of the heaviest elements is a challenging endeavour. A strong influence of relativistic effects, electron-electron correlations, and QED effects, challenge the prediction of the atomic structure. The experimental investigation of elements beyond Z=100 is further complicated by their limited availability and short half-lives as well as their experimentally unknown atomic level structure. Recent laser spectroscopy on nobelium (Z=102) in single-atom-at-a-time quantities with the RAdiation Detection Resonance Ionization Spectroscopy (RADRIS) technique opened the path towards laser spectroscopy experiments of yet heavier elements. For the heaviest actinide, lawrencium (Z=103), two ground-state transitions to the $^2S_{1/2}$ state at around 20420 cm^{-1} and to the $^2D_{3/2}$

state at around 28500 cm^{-1}, are predicted. In 2020 and 2022, over 1000 cm^{-1} around the predicted tranisition wavenumbers have been scanned to search for these transitions. In the talk, the current status of the experiment and the data analysis will be presented.

Q 25.3 Wed 11:30 HS 1098

Nuclear Deformation Effects of Highly Charged Ions — •Zewen Sun, Igor A. Valuev, and Natalia S. Oreshkina — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

Nuclear shape effects are theoretically investigated in terms of corrections to the electronic binding and transition energies and g factors. The corrections are numerically calculated for the widest possible range of nuclei, consisting over 1100 different samples. By solving the Dirac equation with deformed and non-deformed nuclear shapes, i.e. Fermi and deformed Fermi nuclear charge distributions, we separate the deformation effect in binding energies and wavefunctions. The model parameters for the two charge distributions are determined from experimental data. In addition, the importance of deformation effects for the process of searching for new physics is examined.

Q 25.4 Wed 11:45 HS 1098

Towards a direct high-precision measurement of the nuclear magnetic moment of $^3He^{2+}$ with 1ppb accuracy. — •Ankush Kaushik[1], Stefan Dickopf[1], Marius Müller[1], Annabelle Kaiser[1], Ute Beutel[1], Stefan Ulmer[2,3], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]RIKEN, Wako, Japan — [3]HHU Düsseldorf, Germany

Accurate magnetic field measurements are of apparent importance in the field of fundamental physics [1]. However, the accuracy of the current standard in magnetometry, water NMR probes, is limited by the complex molecular structure. With a direct parts-per-billion measurement of the nuclear magnetic moment of $^3He^{2+}$ in a Penning trap, we aim to overcome this limitation and establish hyperpolarised ^3He probes as the new standard. To this end, spin flips of a single nucleon, indicated by miniature frequency changes, need to be detected over background of frequency fluctuations. Since the latter fluctuations are directly proportional to the motional energy, preparing particles at micro eV energies is essential [2]. To address this constraint we designed a new type of Penning trap that enables fast energy measurements while simultaneously allowing the efficient preparation of particles at the required energies. As such, the new trap will be a key element for a successful measurement. Its design and expected performance will be presented.

[1] Mooser *et al.*, J. Phys.: Conf. Ser. 1138 012004 (2018)
[2] Ulmer *et al.*, Physical Review Letters, 106(25) 253001 (2011)

Q 25.5 Wed 12:00 HS 1098

Characterization of an XUV Frequency Comb by Spectroscopy of Rydberg States — •Lennart Guth, Jan-Hendrik Oelmann, Tobias Heldt, Nick Lackmann, Janko Nauta, Thomas Pfeifer, and José R. Crespo López-Urrutia — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

We aim to exploit ultra-narrow transitions in highly charged ions (HCIs) for novel frequency standards and fundamental physics studies. Due to the strong binding of electrons to the nucleus, these transitions are in the extreme ultraviolet (XUV), where narrow-bandwidth laser sources are not commercially available. Therefore, we have built an XUV frequency comb that transfers the coherence of a near-infrared (NIR) comb to the XUV by high harmonic generation (HHG) [1]. To achieve the required intensity ($I_{peak} > 10^{13}\,W/cm^2$) for HHG, we amplify an NIR comb to 80 W in a chirped pulse fiber amplifier and resonantly overlap them in a passive femtosecond enhancement cavity. Our system generates harmonics up to 40 eV and with μW of power each.

We will give an overview of the current status of our experiment and discuss our plans for resonance-enhanced two-photon ionization to resolve the XUX-comb structure. In our spectroscopy approach, we excite argon with one photon from a referenced comb tooth of the 13^{th} harmonic, followed by ionization with a narrow-bandwidth NIR cw-laser. We record the momentum of the released electrons using the velocity map imaging technique to ensure the correct Rydberg state.

[1]J. Nauta et al., Opt. Lett. 45, 2156-2159 (2020)

Q 25.6 Wed 12:15 HS 1098

A Cryogenic Paul Trap Experiment for Laser Spectroscopy of the ^{229m}Th Nuclear Clock Isomer — •Kevin Scharl[1], Georg Holthoff[1], Mahmood I. Hussain[1], Markus Wiesinger[1], Daniel Moritz[1], Lilli Löbell[1], Tamila Rozibakieva[1], Sandro Kraemer[1,2], Benedict Seiferle[1], Shiqian Ding[3], Florian Zacherl[1], and Peter G. Thirolf[1] — [1]LMU Munich — [2]KU Leuven, Belgium — [3]Tsinghua University, Beijing, China

^{229}Th plays a unique role in the nuclear landscape because of its low-lying isomeric first excited state at 8.338 ± 0.024 eV, thus accessible via modern VUV-laser systems. A nuclear clock based on the thorium isomer holds promise not only to push the limits of high-precision time keeping, but also to contribute to dark matter and other fundamental physics research as a novel type of quantum sensor.

The cryogenic Paul trap experiment currently operated at the LMU Munich is primarily designed for long ion storage times, which allows to measure the still unknown ionic lifetime of the isomer. This quantity is expected to be several thousands of seconds and is essential for the realization of a nuclear frequency standard. In a second step, the setup will be a platform for VUV spectroscopy of the isomer, paving the way towards a first nuclear clock prototype.

In this talk, the building blocks of the experimental setup for trapping and sympathetic laser cooling of $^{229}Th^{3+}$ by $^{88}Sr^+$ are presented and the status of first preparatory measurements is discussed.

This work was supported by the European Research Council (ERC) (Grant agreement No. 856415) and BaCaTec (7-2019-2).

Q 25.7 Wed 12:30 HS 1098

Tests of QED with hydrogenlike helium and tin ions and high-precision theory of the bound-electron g-factor — •Bastian Sikora, Vladimir A. Yerokhin, Zoltan Harman, and Christoph H. Keitel — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

The g-factor of electrons bound in hydrogenlike ions can be measured and calculated with high accuracy. In recent collaborations, the experimental and theoretical g-factors of the bound electron in hydrogenlike $^3He^+$ and $^{118}Sn^{49+}$ ions were found to be in excellent agreement [1,2]. We present the theory of the bound-electron g-factor of hydrogenlike ions, as well as the status of two-loop QED calculations aimed to improve the uncertainty of theoretical bound-electron g-factors in the high-Z regime [3]. Such calculations will enable improved tests of QED in planned experiments in the near future and are relevant for the determination of fundamental constants such as the electron mass or the fine-structure constant α as well as searches for physics beyond the standard model.

[1] A. Schneider, B. Sikora, S. Dickopf, et al., Nature **606**, 878 (2022)
[2] J. Morgner, B. Tu, C. M. König, et al., Nature **622**, 53 (2023)
[3] B. Sikora, V. A. Yerokhin, N. S. Oreshkina, et al., Phys. Rev. Research **2**, 012002(R) (2020)

Q 25.8 Wed 12:45 HS 1098

Ionization potential evaluation by Rydberg analysis in iron with resonance ionization spectroscopy — •Thorben Niemeyer[1], Sebastian Berndt[1], Christoph E. Düllmann[1,2,3], Tom Kieck[2,3], Jung-Bog Kim[4], Nina Kneip[5], Dominik Studer[1], and Klaus Wendt[1] — [1]Johannes-Gutenberg-Universität, Mainz — [2]GSI Zentrum für Schwerionenforschung, Darmstadt — [3]Helmholtz-Institut, Mainz — [4]Korea National University of Education, Cheongju — [5]Leibniz Universität, Hannover

The energetic position of high-lying Rydberg levels and their convergence limit, defining the ionization potential (IP), are characteristic properties for every element and give insights into its specific atomic structure. As a well suited technique, Resonance Ionisation Mass Spectrometry was applied to develop a new two-step ionization scheme in the atomic spectrum of iron using ti:sa lasers, involving frequency doubling and trippling. Literature data is complemented by numerous newly found even parity Rydberg levels. The IP, obtained through the Rydberg-Ritz formalism, is in perfect agreement with the literature value, which was obtained by three-step resonance ionization with similar precision. This confirms the independence of the IP from parity. A number of Rydberg series above the IP converging to higher-lying continua of the Fe ion were measured and analysed.

The set of data provides the basis for applying RIMS to the EU PrimA-LTD project, for which radioactive Fe-55 ions are implanted into metallic magnetic microcalorimeters for precision studies on the electron-capture decay of this isotope.

Q 26: Ultracold Molecules (joint session Q/MO)

Time: Wednesday 11:00–13:00 Location: HS 1015

Invited Talk Q 26.1 Wed 11:00 HS 1015

Ultracold interactions between ions and polar molecules — •Leon Karpa — Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany

Ultracold molecules stand out as a promising candidate in a broad spectrum of advanced applications including quantum chemistry, fundamental physics, quantum simulations and information science. Studies of neutral molecular quantum gases and ultracold ion-neutral interactions are two largely complementary interdisciplinary fields that nonetheless share the vision of understanding molecular systems of ever-increasing complexity, and ultimately controlling their properties. In my talk, I will discuss recent advances and challenges in these research domains and how methods from both fields can be used to combine atomic ions with quantum gases of polar molecules. The resulting complex yet precisely controllable system exhibits a hierarchy of tunable attractive and repulsive interactions of different scales, enabling a range of novel experiments and applications. This includes studies of dynamical properties of ultracold polar molecules, ion-molecule collisions in the quantum dominated regime, and the potential formation of ion-molecule many-body bound states.

Q 26.2 Wed 11:30 HS 1015

Developing a Hybrid Tweezer Array of Rydberg Atoms and Polar Molecules — •Kai Voges, Daniel Hoare, Yuchen Zhang, Qinshu Lyu, Jonas Rodewald, Ben Sauer, and Michael Tarbutt — Centre for Cold Matter, Imperial College London, UK

Hybrid tweezer arrays of atoms and molecules are a novel and versatile platform for quantum science and technology. The combination of Rydberg atoms with their large electric dipole moment and polar molecules with their rich level structure and long state coherence times makes this approach a promising candidate for quantum simulation [1] and computing [2,3].

In this talk, I present our efforts to build a hybrid tweezer array based on ultracold Rb atoms and directly laser-coolable CaF molecules. I discuss the advantages and challenges of using such a hybrid system and present our preparation procedures for the atoms and molecules. Furthermore, I show our efforts in trapping and imaging individual atoms and molecules and present our ideas for loading both species into separate tweezer arrays.

Our approach will make it possible to construct arbitrary patterns of atoms and molecules. Through the dynamic rearrangement of tweezers and the long-range interactions mediated by Rydberg atoms, this hybrid platform will be a compelling candidate for scalable quantum computing.

[1] J. Dobrzyniecki *et al.*, PRA **108**, 052618 (2023)
[2] C. Zhang *et al.*, PRX Quantum **3**, 030340 (2022)
[3] K. Wang *et al.*, PRX Quantum **3**, 030339 (2022)

Q 26.3 Wed 11:45 HS 1015

Quantum Dynamics of Two Composite Bosons on a One-Dimensional Lattice — •Caroline Stier, Andreas Buchleitner, and Gabriel Dufour — Physikalisches Institut der Albert-Ludwigs-Universität Freiburg

We study how the dynamics of two composite bosons on a one-dimensional lattice are affected by their constituents' quantum statistics as well as their initial state. We formulate an effective Hamiltonian assuming that the two composites – consisting either of two elementary fermions or two elementary bosons – are tightly bound objects. The contact interactions between the elementary constituents are chosen such that the resulting composite particles do not interact when they are located on the same site. However, due to the exchange of identical constituents, the composites experience an effective nearest-neighbor interaction if they are located on adjacent sites. We solve the Schrödinger equation analytically and perform numerical simulations of the dynamics from several initial configurations. In particular, we find that the composites can form a bound state whose group velocity depends strongly on the nature of their constituents.

Q 26.4 Wed 12:00 HS 1015

Non-abelian invariants in periodically-driven quantum rotors — •Volker Karle, Areg Ghazaryan, and Mikhail Lemeshko — Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg

This presentation explores the role of topological invariants in the non-equilibrium dynamics of periodically-driven quantum rotors, inspired by experiments on closed-shell diatomic molecules driven by periodic, far-off-resonant laser pulses. This approach uncovers a complex phase space with both localized and delocalized Floquet states. We demonstrate that the localized states are topological in nature, originating from Dirac cones protected by reflection and time-reversal symmetry. These states can be modified through laser strength adjustments, making them observable in current experiments through molecular alignment and observation of rotational level populations. Notably, in scenarios involving higher-order quantum resonances leading to multiple Floquet bands, the topological charges become non-Abelian. This results in the remarkable finding that the exchange of Dirac cones across different bands is non-commutative, enabling non-Abelian braiding, paving the way for the study of controllable multi-band topological physics in gas-phase experiments with small molecules, as well as for classifying dynamical molecular states by their topological invariants.

Q 26.5 Wed 12:15 HS 1015

From rotational decay of diatomic molecules to quantum friction — •Nicolas Schüler, Omar Jesús Franca Santiago, and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, Germany

We study the rotational motion of diatomic molecules in free space and interacting with the quantum electromagnetic field [1]. Using macroscopic quantum electrodynamics [2], we obtain the rotation-dependent decay rates of the molecule. By analyzing the behavior of the resulting rates at zero and finite temperature, we find a connection between the decelerating rotational dynamics and quantum friction.

Invited Talk Q 26.6 Wed 12:30 HS 1015

Quantum Logic Spectroscopy of the Hydrogen Molecular Ion — David Holzapfel, Fabian Schmid, Nick Schwegler, Oliver Stadler, Martin Stadler, Jonathan Home, and •Daniel Kienzler — Otto-Stern-Weg 1, 8093 Zurich, Switzerland

I will present our latest results, implementing pure quantum state preparation, coherent manipulation, and non-destructive state readout of the hydrogen molecular ion H_2^+. The hydrogen molecular ion H_2^+ is the simplest stable molecule, and its structure can be calculated ab-initio to high precision. However, challenging properties such as high reactivity, low mass, and the absence of rovibrational dipole transitions have thus far strongly limited spectroscopic studies of H_2^+. We trap a single H_2^+ molecule together with a single beryllium ion using a cryogenic Paul trap apparatus, achieving trapping lifetimes of 11 h and ground-state cooling of the shared axial motion [1]. With this platform we have recently implemented *Quantum Logic Spectroscopy* of H_2^+. We utilize helium buffer-gas cooling to prepare the lowest rovibrational state of ortho-H_2^+ (rotation $L = 1$, vibration $\nu = 0$). We combine this with quantum-logic operations between the molecule and the beryllium ion for preparation of single hyperfine states and non-destructive readout, and demonstrate Rabi flopping on on several hyperfine transitions. Our results pave the way to high-precision spectroscopy studies of H_2^+ which will enable tests of theory, metrology of fundamental constants, and an optical molecular clock.

[1] N. Schwegler, D. Holzapfel, M. Stadler, A. Mitjans, I. Sergachev, J. P. Home, and D. Kienzler, Phys. Rev. Lett. 131, 133003 (2023)

Q 27: Phase Transitions

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

Invited Talk Q 27.1 Wed 11:00 Aula

Engineering of many-body states in a driven-dissipative cavity QED system — Rodrigo Rosa-Medina[1], Fabian Finger[1], Nicola Reiter[1], Jakob Fricke[1], Panagiotis Christodoulou[1], Davide Dreon[2], Alexander Baumgärtner[1], Simon Hertlein[1], Justyna Stefaniak[1], David Baur[1], Dalila Rivero[1], Gabriele Natale[1], Tilman Esslinger[1], and •Tobias Donner[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]PASQAL SAS, 7 Rue Leonard de Vinci, 91300 Massy, France

Exposing a many-body system to external drives and losses can fundamentally transform the nature of its phases, and opens perspectives for engineering new properties of matter. How such characteristics are related to the underlying microscopic processes is a central question for our understanding of materials. A versatile platform to address it are quantum gases coupled to the dynamic light fields inside optical resonators. This setting allows to create synthetic many-body systems with tunable, well-controlled dissipation channels, and at the same time to induce cavity-mediated long-range atom-atom interactions. By engineering the involved light field modes, we study in real-time the dynamics of a phase transition between two such crystals. When the dissipation via cavity losses and the coherent timescales are comparable, we find a regime of limit cycle oscillations leading to a topological pumping of the atoms. In a second set of experiments, we make use of the cavity-mediated interaction to induce the formation of pairs of correlated atoms. We demonstrate that this process is based on the amplification of vacuum fluctuations.

Q 27.2 Wed 11:30 Aula

Dissipative cooling of many-body states realized with Rydberg atoms — •Katharina Brechtelsbauer[1], Thierry Lahaye[2], Antoine Browaeys[2], and Hans Peter Büchler[1] — [1]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, 91127 Palaiseau Cedex, France

Dissipative preparation of quantum states offers a promising alternative to the adiabatic approach, which is often limited to small system sizes due to gap-closings near quantum phase transitions. In this work we propose a setup for preparing many-body states in systems of Rydberg atoms. The idea is to couple the system to a dissipative bath of additional Rydberg atoms via dipolar exchange interactions, such that the system is dissipatively driven into a certain stationary state. The selection of this final state is based on energy conservation, where the detuning between system and bath is tuned to ensure that the preferred decay channels are stronger than other ones. Depending on the exact form of the system-bath interactions the setup can be used to add excitations to the system or to cool into a certain system eigenstate while conserving the number of excitations.

Q 27.3 Wed 11:45 Aula

Phase transition and higher-order mean-field theory of chiral waveguide QED — •Kasper Jan Kusmierek[1], Max Schemmer[2], Sahand Mahmoodian[3], and Klemens Hammerer[4] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Germany — [2]Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO), 50019 Sesto Fiorentino, Italy — [3]Centre for Engineered Quantum Systems, School of Physics, The University of Sydney, Sydney, NSW 2006, Australia — [4]Institute for Theoretical Physics, Leibniz University Hannover, Germany

Waveguide QED with cold atoms provides a potent platform for the study of non-equilibrium, many-body, and open-system quantum dynamics. Even with weak coupling and strong photon loss, the collective enhancement of light-atom interactions leads to strong correlations of photons arising in transmission. Here we apply an improved mean-field theory based on higher-order cumulant expansions to describe the experimentally relevant, but theoretically elusive, regime of weak coupling and strong driving of large ensembles. We determine the transmitted power, squeezing spectra and the degree of second-order coherence. In the regime of very large drive and atom numbers we observe an non-equilibrium phase transition. This reveals the important role of many-body and long-range correlations between atoms in steady state.

Q 27.4 Wed 12:00 Aula

Transition between Directed Percolation and Mean Field Universality in a driven, dissipative Rydberg gas — •Simon Ohler, Daniel Brady, and Michael Fleischhauer — RPTU Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern

The spread of excitations in a laser driven gas of Rydberg atoms under facilitation conditions bears many similarities to epidemics. Increasing the drive strength, a non-equilibrium phase transition from an absorbing to an active phase occurs. We analyze the dynamics of the Rydberg many-body system in the facilitation regime close to the critical point as a function of the gas temperature by means of Monte-Carlo simulations. While at very low temperatures the phase transition belongs to the directed percolation universality class, the dynamical critical exponent crosses over into a mean field behavior with increasing temperature, reminiscent of anomalous directed percolation. Additionally, we consider the avalanche-like spread of excitation cascades. For all temperatures the system exhibits power-law distributed avalanche sizes, which are key signatures of self-organized criticality, a process believed to lie at the heart of many critical phenomena in nature.

Q 27.5 Wed 12:15 Aula

Nanomechanically-induced quantum phase transition to a self-organized density-wave BEC — •Milan Radonjić[1,2], Leon Mixa[1], Axel Pelster[3], and Michael Thorwart[1] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Physics Department and Research Center OPTIMAS, University Kaiserslautern-Landau, Germany

We study nonequilibrium quantum phase transition (NQPT) in a hybrid quantum many-body system consisting of a vibrational mode of a nanomembrane interacting optomechanically with a cavity, whose output light couples to two internal states of an ultracold Bose gas held in an external quasi-1D box potential. For small effective membrane-atom couplings, the system is in a homogeneous BEC ground state, with no membrane displacement. Depending on the transition frequency between the two internal atomic states, either one or both internal states are occupied. By tuning the two couplings outside the respective critical regions, the system transitions to a symmetry-broken self-organized BEC phase, which is characterized by a sizeably displaced membrane and density-wave-like BEC profiles. This NQPT is both discontinuous and continuous for a certain interval of transition frequencies, and purely discontinuous outside of it.

Q 27.6 Wed 12:30 Aula

Low-energy modes in a trapped dipolar supersolid — •Paul Uerlings[1], Jens Hertkorn[1], Kevin Ng[1], Fiona Hellstern[1], Lucas Lavoine[1], Ralf Klemt[1], Tim Langen[1,2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Atominstitut, TU Wien, Stadionallee 2; 1020 Vienna, Austria

A supersolid is a phase of matter that combines the crystal-like periodic density modulation of a solid with the frictionless flow of a superfluid, simultaneously breaking both the global U(1) gauge symmetry and the translational symmetry. Breaking these two symmetries gives rise to two types of collective modes, called the Nambu-Goldstone and amplitude Higgs mode. We theoretically and experimentally investigate the excitation spectrum of a trapped dipolar quantum gas across the Bose-Einstein condensate to supersolid phase transition. In order to experimentally observe these excitations, we prepare a ultracold quantum gas of ^{162}Dy in an optical dipole trap with variable geometry. We compare our experimental results to numerical simulations of the extended Gross-Pitaevskii equation and the Bogoliubov-de-Gennes equations. The observed low-energy modes reveal the existence of the two distinct amplitude Higgs and Nambu-Goldstone modes that emerge in our system at the phase transition point. Our findings extend earlier work on the obervation of the Nambu-Goldstone mode and theoretical predictions on the amplitude Higgs mode.

Q 27.7 Wed 12:45 Aula

Observation of spatial first-order coherence in an optical

quantum gas in a box — •Leon Espert Miranda, Andreas Redmann, Kirankumar Karkihalli Umesh, Frank Vewinger, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany

The emergence of long-range correlations that span the entire system is a manifestation of phase transitions between different states of matter. Experimentally, such field correlations in quantum gases can be obtained by investigating the degree of first-order spatial coherence, for example, in interference experiments. Here we report a measurement of the build-up of quasi long-range correlations in a two-dimensional optical quantum gas trapped inside a box potential as the total number of particles in the gas is increased. The correlation information is obtained by measurements of the photon gas distribution in momentum space as well as interferometry of the dye-filled optical microcavity emission. We observe different scalings of the coherence length for the normal and quantum degenerate gas. Moreover, by studying different sizes of the box trap, we demonstrate that Bose-Einstein condensation sets in as soon as the coherence length exceeds the system size.

Q 28: Fermionic Quantum Gases I (joint session Q/A)

Time: Wednesday 11:00–13:00 Location: HS 1199

Q 28.1 Wed 11:00 HS 1199

Bulk-boundary correspondence for anomalous Floquet topological insulators: winding number and micromotion area — •Luca Asteria[1,2], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut for Quantum Physics, Hamburg University — [2]Hamburg Centre for Ultrafast Imaging — [3]Center for Optical Quantum Technologies, Hamburg University

Driven Floquet systems can realize topological phases with no static counterparts. So-called anomalous Floquet topological insulators (AFTIs) break the bulk-boundary correspondence based on the Chern number. The winding number, which predicts the number of edge modes instead, is calculated from the time evolution operator of the bulk states within one driving period. While in non-driven system the Chern number also predicts the quantization of the transversal Hall conductance in the systems bulk, for AFTIs so far, no dynamical bulk observable directly connected to the winding number was identified. Here we show that the winding number is directly connected to such an observable, namely the area enclosed by an initially localized particle during a Floquet period. In particular, in the associated fine-tuning limit of the Floquet protocol, we show that the winding number is exactly given by this area in units of half the unit cell area. Such a direct real-space detection of anomalous topology could be realized in several quantum simulation platforms. We also show how, by choice of the associated fine-tuning protocol, the number and the speed of coexisting edge modes could be arbitrarily tuned, which may be of relevance for quantum information and communication applications.

Q 28.2 Wed 11:15 HS 1199

Bosonization analysis for a ring of SU(N) fermions with a single impurity — •Andreas Osterloh[1], Wayne Chetcuti[1], Juan Polo[1], and Luigi Amico[1,2] — [1]Technology Innovation Institute, Masdar City & Yas Island, P.O. box 9639 Abu Dhabi, UAE — [2]Dipartimento di Fisica e Astronomia Ettore Majorana, Via S. Sofia 64, 95127 Catania, Italy

We are using a bosonization analysis for handling a ring lattice carrying SU(N) fermions. Similar as for bosons, the impurity results in a boundary sine-Gordon field theory. Their effect on the charge and SU(N)-spin parts of the fields is analyzed and the charge-current is calculated. Its interconnection with the observed fractionalization results is discussed in detail.

Q 28.3 Wed 11:30 HS 1199

Heidelberg Quantum Architecture: Fast and modular programmable quantum simulation — •Tobias Hammel[1], Maximilian Kaiser[1], Philipp Preiss[2], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut, Heidelberg, Germany — [2]MPQ, Garching, Germany

Heidelberg Quantum Architecture (HQA) is a new ^{6}Li quantum gas experiment providing a fast, versatile, and expandable platform for programmable quantum simulation. In this talk, we report on the realization of these characteristics in our new ^{6}Li experiment and first experimental findings.

Key components of the experiment are easily exchangeable optical modules, which include tweezers, a Digital Mirror Device, optical dipole traps, a tuneable 2D confinement and single atom and spin resolved imaging. Our broad and easy to expand toolbox will enable experimental cycles of up to 10Hz in the near future and allow for fast data collection and on-demand quantum simulation.

The current status of the experiment features a 2D-MOT with loading rates of larger than 10^8atoms/s loaded into a 3D-MOT. From there the atoms are loaded via two optical dipole traps into a tweezer, in which we can rapidly evaporate down to degeneracy.

Q 28.4 Wed 11:45 HS 1199

Emergence of a collective excitation in a mesoscopic Fermi gas — •Johannes Reiter, Philipp Lunt, Paul Hill, Maciej Galka, and Selim Jochim — Physikalisches Institut, Univeristät Heidelberg, 69120 Heidelberg, Deutschland

Understanding the elementary excitations of strongly interacting many-body systems in terms of the independent motion of individual particles and their collective behaviour constitutes a pervasive problem in many fields ranging from nuclear physics to cold atoms [1,2].

In this talk, we present the spectroscopic observation of the emergence of the radial quadrupole mode from the confinement dominated excitation spectrum in a mesoscopic Fermi gas trapped in an optical tweezer. By systematically tuning the interparticle interactions across the BEC-BCS crossover we investigate the stability of the mode against single particle excitations and showcase the measurement of its coherent properties. Finally, we discuss the prevailing competition between the confinement and interaction energy delineating constraints on the manifestation of collective behaviour in finite-size quantum systems.

[1] B. Mottelson, Science 193 (4250), 287-294 (1976) [2] S. Giorgini et al., Rev.Mod.Phys. 80, 125 (2008)

Q 28.5 Wed 12:00 HS 1199

Observation of pairing in a strongly correlated few-fermion system — •Carl Heintze, Sandra Brandstetter, Karen Wadenpfuhl, Philip Lunt, Keerthan Subramanian, Marvin Holten, Maciej Galka, and Selim Jochim — Universität Heidelberg

Strong correlations and entanglement are crucial for many phenomena of modern physics as high temperature superconductivity and the expansion of the early universe. They pose a challenging task for theorists and experimentalists. We address this problem with few body systems of up to 12 particles. They are large enough to build up complex correlations but are experimentally well controlled, allowing us to extract microscopic observables as atom-atom correlations [1]. We work with quasi 2D systems which are prepared in their quantum mechanical ground state with fixed atom number. We use two different matterwave magnification techniques to measure the momentum or position of every single particle in a spin-resolved way. Recently we observed hydrodynamic behaviour in an expanding few particle system accompanied by the formation of atom pairs [2]. As a next step we aim to gain a deeper understanding of pairing by studying real space correlations in the trapped system. Additionally, we want to use RF-spectroscopy to extract the energy spectrum [3]. In the future we want to measure the contact, prepare repulsively interacting systems and observe interference of identical few body systems.

[1] Holten et al. Nature 606 (2022) [2] Brandstetter et al. arXiv: 2308.09699v1 [cond-mat.quant-gas] [3] Wenz et al. Science 342 (2013)

Q 28.6 Wed 12:15 HS 1199

Realisation of a two-particle Laughlin state with rapidly rotating fermions — •Paul Hill[1], Philipp Lunt[1], Johannes Reiter[1], Maciej Galka[1], Philipp Preiss[2], and Selim Jochim[1] — [1]Physikalisches Institut Heidelberg — [2]Max-Planck-Institut für Quantenoptik

The fractional quantum Hall (FQH) effect features remarkable states that due to their strongly correlated nature and exotic topological properties have stimulated a rich body of research going far beyond the condensed matter community, where the effect was originally discovered. One fundamental class of FQH states is described by the celebrated Laughlin wavefunction, which accounts for a large number of plateaus in the Hall resistivity and already exhibits interesting anionic, fractionally charged quasi-particle excitations.

Here we present the direct realisation of the two-particle Laughlin wavefunction by rapid rotation of two interacting spinful fermions in a tight optical tweezer. We owe this result to our newly established experimental tools allowing us to precisely shape and modulate our optical potentials using coherently interfering laser fields.

Our observations reveal distinctive features of the Laughlin wavefunction, including a ground state distribution in the center-of-mass motion, a vortex distribution in the relative motion, correlations in the relative angle of the two particles, and the suppression of interparticle interactions. This achievement represents a significant step towards scalable experiments, enabling the atom-by-atom assembly of fermionic fractional quantum Hall states in quantum simulators.

Q 28.7 Wed 12:30 HS 1199

Imaging strongly correlated states of the Fermi-Hubbard model — •Petar Bojović[1,2], Thomas Chalopin[1,2], Dominik Bourgund[1,2], Si Wang[1,2], Titus Franz[1,2], Johannes Obermeyer[1,2], Timon Hilker[1,2], and Immanuel Bloch[1,2,3] — [1]Max Planck Institute of Quantum Optics — [2]Munich Center for Quantum Science and Technology — [3]Ludwig Maximilian University

The Fermi-Hubbard model is a simple yet powerful model that captures much of the essential physics of high-Tc superconductors. It is naturally realized in our Quantum Gas Microscope, where we load fermionic 6Li atoms into optical lattices and conduct site-resolved measurements of their spin and density. Our experiment serves as a powerful tool to explore quantum phases of a Fermi Hubbard diagram.

An example is the pseudogap phase, which exists above the superconducting transition temperature and is suggested to result from preformed dopant pairs. Our experiment allows us to calculate two-point and multi-point correlation functions between spins and/or dopants and explore the phase diagram. Higher-order correlators directly reveal intriguing features about the interaction of dopants or excitations with the antiferromagnetic background.

Here, I will present measurement of multi-point spin and charge correlators as a function of doping and temperature. We observe significant higher order correlations at low temperature and close to half filling, signaling the emergence of strongly correlated states. This formalism opens a new outlook to the characterization of the real-space and low temperature states of the Fermi-Hubbard model.

Q 28.8 Wed 12:45 HS 1199

Exploring stripe phase in Fermi-Hubbard model with a quantum gas microscope — •Si Wang[1,2], Dominik Bourgund[1,2], Thomas Chalopin[1,2], Petar Bojović[1,2], Titus Franz[1,2], Sarah Hirthe[4], Immanuel Bloch[1,2,3], and Timon Hilker[1,2] — [1]Max-Planck Institute of Quantum Optics, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Ludwig Maximilian University of Munich, Munich, Germany — [4]ICFO - The Institute of Photonic Sciences, Castelldefels, Spain

The Fermi-Hubbard model is crucial for understanding physics in quasi 2D layers of high-Tc cuprate superconductors. Investigating the profound connection between d-wave superconductivity and stripes, essential elements in cuprate ordered phases, promises valuable insights. In the isotropic Fermi-Hubbard model, the interplay between the kinetic energy of the dopants and the magnetic energy of the AFM spin order governs the system and reduces the energy scale for stripe order well beyond the reach of state-of-the-art cold-atom quantum simulators. To address this, we engineered a mixed-dimensional system, selectively suppressing particle tunneling along one direction while maintaining 2D spin interactions. This innovative approach tilts the balance in the competition between kinetic and magnetic energies, and thus elevates characteristic energy scales for collective effects, allowing us to observe signatures of stripes in our quantum simulator. Notably, recent discoveries indicate that mixed-dimensional systems can exhibit a distinct manifestation of high-Tc superconductivity, emphasizing the significance of our research endeavors in advancing this field.

Q 29: Photonics

Time: Wednesday 11:00–13:00 Location: HS 1221

Q 29.1 Wed 11:00 HS 1221

Thermally Expanded Core Fiber: a Novel Platform for Meta-Fibers — •Mohammadhossein Khosravi[1,2], Jisoo Kim[1,2], Malte Plidschun[1,2], Torsten Wieduwilt[1], Matthias Zeisberger[1], and Markus Schmidt[1,2,3] — [1]Leibniz Institute of Photonic Technology, 07745, Jena, Germany — [2]Abbe Center of Photonics and Faculty of Physics, FSU Jena, 07745, Jena, Germany — [3]Otto Schott Institute of Material Research, FSU Jena, 07745, Jena, Germany

Meta-Fibers, incorporating 3D-printed Metalens technology into optical fiber facets, offer versatility in imaging, optical trapping, and electromagnetic wave manipulation. While Single-Mode Fiber (SMF) is prized for its precise output, its limited mode field diameter presents challenges, often necessitating fusion splicing with Multi-Mode Fiber (MMF) or intricate 3D-printed structures to expand the usable beam cross-section. However, these methods are complex and risk damaging the Meta-Fiber. This study proposes an alternative solution by replacing SMF with Thermally Expanded Core (TEC) fiber, known for its significantly larger mode field diameter. This novel approach facilitates optical trapping and imaging through the integration of a 3D laser-printed ultra-high numerical aperture metalens into TEC fibers, demonstrating effective performance in diverse environments. The results not only broaden the applications of Meta-Fiber but also present a more efficient, robust, and scalable solution for optical wavefront manipulation. Moreover, the study underscores the potential of TEC fibers in advancing optics and photonics technology.

Q 29.2 Wed 11:15 HS 1221

Overview of waveguides based on Pancharatnam-Berry Phase — •Stree Vithya Arumugam[1], Chandroth P Jisha[1], Alessandro Alberucci[1], and Stefan Nolte[1,2] — [1]Friedrich Schiller University, Institute of Applied Physics, Albert-Einstein-Str. 15, 07745, Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745, Jena, Germany

Dielectric optical waveguides utilize refractive-index modulation to confine light by manipulating the dynamic phase gained across the beam cross-section. Recently, it was shown that waveguides based on the Pancharatnam-Berry phase (PBP) can guide light without any transverse refractive-index gradient. A PBP waveguide is realizable in an anisotropic material, if a point-dependent rotation of the optic axis across the transverse plane is accompanied by a periodic rotation along the propagation direction. Ideally, the modulation period must be synchronized with the natural rotation of light polarization to permit a net accumulation of PBP: in this case a spin-dependent effective trapping potential proportional to the rotation axis emerges.

Here, we theoretically investigate the properties of the PBP waveguide addressing the robustness of the confinement in the presence of a mismatch between the birefringence length and the modulation period. In the spatial domain, such a mismatch provides an additional degree of freedom in controlling the polarization structure of the quasi-modes. In the temporal domain, the PBP waveguides exhibit a higher optical dispersion than GRIN waveguides due to the inherent resonance condition.

Q 29.3 Wed 11:30 HS 1221

Multiple quasi-phase-matched dispersive waves generation in dispersion oscillating liquid-core-fibers — •Xue Qi and Markus A. Schmidt — Leibniz Institute of Photonic Technology, Albert-Einstein-Str. 9, 07745 Jena, Germany

Widely wavelength-tunable femtosecond light sources play a vital role in many research fields and technologies. Although fiber lasers are on the edge in the development of such sources, the widespan spectral tunability of femtosecond pulses remains a prime challenge. Dispersive wave (DW) generation, offers a powerful approach to fulfill these demands. In this work, the concept of quasi-phase-matching (QPM) for multi-order DW formation with record-high spectral fidelity and femtosecond durations is exploited. We introduce liquid(CS_2)-core fibers (LCFs) with periodically controlled dispersion of a higher-order mode

along the fiber, achieved by axial modulation of the liquid core diameter. The implementation of LCFs with periodically varying core diameters is realized by controlled partial collapses of the hole of a fiber-type silica capillary and subsequently filling it with CS2. By launching femtosecond pulses (1570 nm, 36 fs) through an s-waveplate and an in-coupling lens to excite the TE01-mode in the 5 cm long LCFs, multiple QPM-related spectral peaks are formed on both sides of the DW0 (referred as the zero-order DW, at 2.4 μm) extending the spectrum to 3 μm. The density of these QPM-DWs can be tuned by the period length of the diameter-modulated LCFs. Optical experiments and nonlinear simulations confirm the conversion process.

Q 29.4 Wed 11:45 HS 1221

Selective Higher Order Mode Excitation in a Nanoprinted Hollow Square-Core Waveguide — •Diana Pereira[1,2], Marta S. Ferreira[1], and Markus A. Schmidt[2] — [1]i3N & Physics Department, University of Aveiro, Portugal — [2]Leibniz Institute of Photonic Technology, Jena, Germany

Tailoring the excitation of higher order modes (HOM) is of great importance across several applications within the photonics field, including optofluidics sensing, nonlinear phenomena generation, imaging, and in fiber communication systems. Nevertheless, effectively exciting specific HOM still remains a challenge. Currently, HOM can be achieved resorting to certain optical devices such as spatial light modulators and modal couplers. However, these devices are not fully integrated in the waveguide, which can impose some drawbacks such as difficult coupling and the requirement of high precision in the alignment. With the recent advancements in the 2-photon polymerization (2PP) printing technology, a novel methodology for the excitation of HOM can be explored. The figures of merit of this method rely on the capability of designing extremely smooth structures at a nanoscale, and with a very high detail accuracy. Thus, new platforms based on a waveguide integrated modulator are being pursuit. Within this context, we present a reliable and highly reproducible method to effectively exciting HOM. Resorting to the 2PP technology, a nano-phase plate integrated into a nanoprinted hollow square core waveguide is proposed. The 580 nm thick phase plate is configured in two different designs, inducing the excitation of the LP11 and LP12 modes.

Q 29.5 Wed 12:00 HS 1221

Engineering and characterization of phase randomness in driven χ^3 optical resonators — •Sayonil Mollah[1], Christopher Spiess[1,2], Meritxell Cabrejo Ponce[1,2], and Fabian Oliver Steinlechner[1,2] — [1]Friedrich Schiller University, Institute of Applied Physics, Abbe Center of Photonics, Albert-Einstein-Strasse 15, Jena 07745, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Strasse 7, Jena 07745, Germany

Optical parametric oscillators (OPO) have long been used as a source of tunable, narrow-linewidth and coherent light in various aspects of photonics. Particularly, the recent applications of twin frequency degenerate OPOs have garnered attention in quantum technologies for quantum random number generation (QRNG). This is due to the randomness of the generated signal/idler fields which causes them to lock on to the pump field, when the gain is above threshold. Since the signal and idler fields are offset by a phase π, the phase sensitive gain gives rise to a bi-phase state.

Here, we present experimental efforts to generate and characterize a bi-phase state from a degenerate OPO in a silicon nitride (χ^3) microresonator and a fiber cavity. The output from a dual wavelength pulse-pumped resonator is collected and measured in time and spectral domains. The degenerate signal is filtered and self-interfered to characterize the phase. Additionally, we perform simulations and theoretical calculations to establish suitable operational regimes for stable oscillation. Our results pave the way for an all optical QRNG with a simplified detection protocol and no post-processing.

Q 29.6 Wed 12:15 HS 1221

Light-propelled anisotropic refractive microswimmers — •Matthias Rüschenbaum[1], Elena Vinnemeier[1], Jörg Imbrock[1], and Cornelia Denz[1,2] — [1]Institute of Applied Physics, Münster, Germany — [2]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

Self-propelled microswimmers offer a wide range of applications, for example in biomedicine or colloidal systems. Among the various drive mechanisms, light-propelled microswimmers offer many advantages such as high biocompatibility and precise control. In our approach, the refraction of light provides a directed propulsion for the particles. These particles have an asymmetric geometry and are several micrometers in size. In addition, chiral particle shapes ensure a rotating motion. The light-driven microswimmers are fabricated by direct laser writing using two-photon polymerization, which enables high versatility and accuracy. The laser light-induced movement is then evaluated and compared for the different particle shapes.

Q 29.7 Wed 12:30 HS 1221

Fabrication of mechanically tunable 3D protein-based hydrogel microstructures by two-photon lithography for onchip cell microenvironments — •Jesco Schönfelder[1], Dustin Dzikonski[1], Dominika Ciechanska[2], Jörg Imbrock[1], Cornelia Denz[3], and Albrecht Schwab[2] — [1]Institute of Applied Physics, University of Münster, Germany — [2]Institute of Physiology II, University of Münster, Germany — [3]Physikalisch-Technische Bundesanstalt, Germany

Microfluidic polydimethylsiloxane (PDMS) devices are a powerful tool for mimicking in-vivo cell microenvironments. PDMS offers high experimental versatility and biocompatibility while microfluidic channels provide laminar flow and allow for thoroughly monitored flow parameters. However, the tunability of mechanical and topological properties of PDMS microchannels is limited by the spatial precision of the applied fabrication method. We utilize two-photon lithography to fabricate spatially intricate 3D protein-based hydrogel structures with sub-micron resolution in order to create defined cell environments with high biocompatibility and tissue-like elasticity. The direct writing procedure allows for fabricated structures to be embedded into microfluidic channels. Via variation of the exposure time and illumination intensity, the mechanical properties of the polymerized media can be tuned. We present results on Young's moduli of the hydrogel structures measured by atomic force microscopy and discuss applications of the 3D microstructures for biophotonic applications.

Q 29.8 Wed 12:45 HS 1221

Characterizing of complex random media and biological tissue with self-consistent quantum field theory — Andreas Lubatsch[1] and •Regine Frank[2,3] — [1]Physikalisches Institut, Rheinische Friedrich Wilhelms Universität Bonn — [2]College of Biomedical Sciences, Larkin University, Miami, Florida, USA — [3]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain

We present a quantum field theoretical method for characterizing disordered complex media with short laser pulses and (OCT). We introduce so called weighted essentially non-oszillatory solvers (WENO) for the analysis of highly nonlinear and discontinuous processes including interference effects and Anderson localization of light in time-of-flight (ToF) and pump-probe experiments. The results are a measure of the coherence of multiple scattering photons in passive matter as well as in soft mat-ter and biological tissue.

[1] A. Lubatsch, R. Frank, Phys. Rev. Research 2, 013324 (2020) [2] D. Huang, et. al., Science 254, 1178 (1991) [3] K. C. Zhou, et. al.,Nat. Photon. 13, 794 (2019)

Q 30: Color Centers I

Time: Wednesday 11:00–13:00 Location: HS 3118

Q 30.1 Wed 11:00 HS 3118

Spectral stability of V2-centres in sub-micron 4H-SiC membranes — •Jonah Heiler[1,2], Jonathan Körber[2], Erik Hesselmeier[2], Pierre Kuna[2], Rainer Stöhr[2], Philipp Fuchs[3], Misagh Ghezellou[4], Jawad Ul-Hassan[4], Wolfgang Knolle[5], Christoph Becher[3], Florian Kaiser[1,2], and Jörg Wrachtrup[2] — [1]MRT Department, Luxembourg Institute of Science and Technology & Department of Physics and Materials Science, University of Luxembourg, Belvaux, Luxembourg — [2]3rd Institute of Physics, University of Stuttgart, Germany — [3]Universität des Saarlandes, Fachrichtung Physik, Saarbrücken, Germany — [4]Department of Physics, Chemistry and Biology, Linköping University, Sweden — [5]Leibniz-Institute of Surface Engineering (IOM), Leipzig, Germany

Colour centres in solids emerge as a promising quantum technology platform, since they inherently provide a spin-photon interface. Overcoming its low photon extraction efficiency requires nanophotonic structuring, which can reduce the colour centres' spectral stability. Here, we focus on silicon vacancy colour centres in the industry's leading third-generation semiconductor silicon carbide and show a systematic large-scale study of their optical properties in sub-μm membranes. We develop a highly reproducible recipe to produce those membranes using chemical mechanical polishing together with reactive ion etching. Further, we observe close-to lifetime limited optical linewidths with almost no signs of spectral wandering in 0.7 μm membranes. Our findings open the avenue for the integration of silicon vacancies into a variety of nanophotonic structures that improve the photon extraction.

Q 30.2 Wed 11:15 HS 3118

Photon-collection enhancement of V2-centers integrated in a cavity-based 4H-SiC antenna. — •Jonathan Körber[1], Jonah Heiler[1,2], Erik Hesselmeier[1], Pierre Kuna[1], Rainer Stöhr[1], Philipp Flad[3], Philipp Fuchs[4], Misagh Ghezellou[5], Jawad Ul-Hassan[5], Wolfgang Knolle[6], Christoph Becher[4], Florian Kaiser[1,2], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, University of Stuttgart, Germany — [2]MRT Department, Luxembourg Institute of Science and Technology & Department of Physics and Materials Science, University of Luxembourg, Belvaux, Luxembourg — [3]4th Physics Institute, University of Stuttgart, Germany — [4]Universität des Saarlandes, Fachrichtung Physik, Saarbrücken, Germany — [5]Department of Physics, Chemistry and Biology, Linköping University, Sweden — [6]Leibniz-Institute of Surface Engineering (IOM), Leipzig, Germany

Color centers in semiconductors promise various applications for quantum technologies. However, due to the typically large refractive indices of the host materials, photons are extracted inefficiently from such color centers, while high photon count rates are a key requirement for many applications. Here, we present the fabrication of a planar, cavity-based antenna based on silver-coated, sub-micron-thin silicon carbide membranes to increase the photon extraction from integrated silicon-vacancy color centers. Further, we report a count rate enhancement of up to one order of magnitude for single, cavity-integrated color centers compared to bulk and find stable, resonant absorption lines at cryogenic temperatures.

Q 30.3 Wed 11:30 HS 3118

Towards Quantum Computing with Divacancies in Silicon Carbide — •Flavie Marquis, Jonah Heiler, and Florian Kaiser — MRT Department, Luxembourg Institute of Science and Technology & Department of Physics and Materials Science, University of Luxembourg, Belvaux, Luxembourg

Colour-centres provide an excellent platform for quantum technology. They enable a pairing of spin-photon interfaces with robust qubits and memories. The nitrogen-vacancy (NV) centre in diamond has lead most of the developments. However, new promising systems are being investigated [1]. Here, we consider stacking-fault divacancies (sf-VVs) in silicon carbide (SiC). The sf-VV centre resembles the diamond-NV in terms of spin level structure, spin-control fidelities, high ODMR contrast at room temperature, nuclear spin control capabilities and adequately high photon count rates [2]. Since sf-VV centres are integrated into a semiconductor host, they benefit from industry technology, such as integration into p-i-n diodes for wavelength tuning [3], as well as mature nanofabrication for improving optical efficiencies [4]. Here, we present our first results on fabrication and control of sf-VVs in SiC at room temperature, including spin coherence times and control fidelities. An outlook towards high-level nuclear spin control within the di-atomic lattice is discussed.

[1] Nat. Photonics 12, 516 (2018)
[2] Nat. Sci. Rev. 9, nwab122 (2022)
[3] Science 366, 1225 (2019)
[4] Nat. Mater. 21, 67 (2022)

Q 30.4 Wed 11:45 HS 3118

Waveguide-coupled single photon source in silicon carbide — •Marcel Krumrein[1], Raphael Nold[1], Flavie Davidson-Marquis[2], Arthur Bourama[1], Erik Hesselmeier[1], Ruoming Peng[1], Lukas Niechziol[1], Di Liu[1], Rainer Stöhr[1], Patrick Berwian[3], Jawad Ul-Hassan[4], Florian Kaiser[2], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, University of Stuttgart, Germany — [2]MRT Department, Luxembourg Institute of Science and Technology, Luxembourg — [3]Fraunhofer Institute for Integrated Systems and Device Technology IISB, Germany — [4]Department of Physics, Chemistry and Biology, Linköping Unversity, Sweden

Spin defects in silicon carbide are promising quantum emitters for quantum information applications. The silicon vacancies V1 and V2 in 4H-SiC possess very promising spin-optical properties, as lifetime-limited emission and a rich nuclear spin bath. However, the collection efficiency of bulk emitters is very poor, leading to low photon count rates, and thus, long measurement times. To address this, we integrate V2 defects into single mode nanobeams [1] and collect the emitted photons by tapered fibers [2]. Here, we present the characterization of the waveguide-fiber interface experimentally and theoretically with coupling efficiencies exceeding 93%. Using this interface, the emission of waveguide-integrated, single V2 centers was proven with saturated photon count rates of 181 kcps. Finally, we perform Rabi and Hahn-Echo sequences to show the accessibility of the defect's spin.

[1] C. Babin et al., Nat. Mater. 21, 67 (2022). [2] M. J. Burek et al., Phys. Rev. Applied 8, 024026 (2017).

Q 30.5 Wed 12:00 HS 3118

Single-photon emission from silicon-vacancy color centers in polycrystalline diamond membranes — •Assegid Flatae[1,2], Florian Sledz[1,2], Haritha Kambalathmana[1,2], Stefano Lagomarsino[3,4], Silvio Sciortino[3,4,5], and Mario Agio[1,2,5] — [1]Laboratory of Nano-Optics, University of Siegen, 57072 Siegen, Germany — [2]Cμ-Research Center of Micro- and Nanochemistry and (Bio)Technology, University of Siegen, 57068 Siegen, Germany — [3]Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, 50019 Sesto Fiorentino, Italy — [4]National Institute of Optics (INO), National Research Council (CNR), 50125 Florence, Ital — [5]National Institute of Optics (INO), National Research Council (CNR), 50125 Florence, Italy

Single-color centers in thin polycrystalline diamond membranes are of interest in integrated quantum photonics and hybrid quantum systems. However, their practical application was so far limited by crystallographic defects, impurities and graphitic grain boundaries. We report on a single-photon source based on silicon-vacancy color centers in a polycrystalline diamond membrane, we discuss the spectroscopic approach and the photophysics, reaching g2(0)= 0.04.

Q 30.6 Wed 12:15 HS 3118

Creation of a single SiV center in nanodiamond by ion implantation — •Tim Buskasper[1,2] and Carsten Schuck[1,2] — [1]Center for Soft Nanoscience, Münster, Germany — [2]Center for Nanotechnology, Münster, Germany

Single photon emitters are a crucial component in the further development of quantum technologies such as quantum computers or quantum key distribution. For this purpose, especially group IV defects in diamond are promising candidates due to their robustness, short lifetime, and large Debye-Waller factor. However, the production of a single color center in (nano)diamonds remains a persistent challenge.

Here, we report on the successful generation of SiV centers in nanodiamonds through ion implantation using a focus ion beam technique, followed by thermal post-treatment. Notably, we present the creation of both: ensembles and a single SiV center in a nanodiamond. The single SiV center exhibits a lifetime of $t_1 = (2.40 \pm 0.17)$ ns and $g(\tau = 0) = 0.08$.

Our fabrication process is enhanced by an automatic mark detection system in our FIB system and in combination with our precise nanoparticle placement technique, the creation approach becomes scalable and semi-automatable. Furthermore, integration of the single nanodiamond into nanophotonic circuits is feasible, paving the way for fully integrated nanophotonic devices.

Q 30.7 Wed 12:30 HS 3118

Spin Control of Silicon-Vacancy Centers in Nanodiamonds — •Marco Klotz[1], Andreas Tangemann[1], Viacheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, University Ulm, Germany — [2]GREMAN, UMR 7347 CNRS, INSA-CVL, Tours University, 37200 Tours, France

For the realization of quantum networks, qubits that can be interfaced with scalable photonic technologies are of major interest. Due to their good optical and spin properties [1], group IV defects in diamond are promising candidates for these applications. We are using negatively-charged silicon-vacancy-centers hosted in nanodiamonds that can be integrated into photonic structures. Compared to bulk diamond, SiVs hosted in a nanodiamond experience less dephasing due to a combination of locally modified phonon density of states and increased ground-state splitting [2]. Hence, they are a candidate for operation above mK temperature, decreasing the technological overhead. Here, we present our progress in characterizing and controlling the electron-spin qubit of a SiV- in a nanodiamond at liquid Helium temperature for future application in quantum networks.

[1] R. Waltrich et al., Two-photon interference from silicon-vacancy centers in remote nanodiamonds, 10.1515/nanoph-2023-0379

[2] M. Klotz et al., Prolonged Orbital Relaxation by Locally Modified Phonon Density of States for the SiV- Center in Nanodiamonds, 10.1103/PhysRevLett.128.153602

Q 30.8 Wed 12:45 HS 3118

Thin-film 4H-silicon carbide-on-Insulator for spin-mechanical applications — •Yan Tung Kong — 3. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

High-quality, wafer-scale, thin-film silicon carbide (SiC) holds significant potential in the realms of modern microelectromechanical systems (MEMS), integrated nonlinear photonic circuits, and quantum photonics. Nevertheless, the properties of thin-film SiC often suffer a significant degradation comparing to bulk crystals, primarily due to surface damage incurred during bonding and thinning processes. In this study, we present a successful demonstration of the complete process flow for thin-film 4H-silicon carbide-on-Insulator (4H-SiCOI). Our approach integrated plasma activation bonding, Chemical Mechanical Polishing (CMP), and Inductively Coupled Plasma Etching (ICP-RIE) techniques, effectively mitigating surface damage and ensuring the production of high-quality thin-film SiC with preserved properties. Furthermore, we fabricated nano-mechanical and photonic SiC devices featuring implanted Si vacancies within our SiC thin films (<1 um). This provides a unique platform for exploring spin-phonon-photon dynamics in nanoscale opto-mechanical devices.

Q 31: Quantum Communication IV

Time: Wednesday 11:00–13:00 Location: HS 3219

Q 31.1 Wed 11:00 HS 3219

Free-Space Quantum Key Distribution at Daylight using the Sodium D_2 Line — •Ilija Funk, Yagana Syed, and Ilja Gerhardt — Leibniz University Hannover, light & matter group, Appelstrasse 2, 30167 Hannover

Quantum key distribution is a promising pathway to secure communication in the future. Currently, quantum communication channels usually are realized through a fiber or a free-space network. While the latter offers much longer transmission distances of hundreds of kilometers compared to fiber links, it suffers from reduced transmission rates during daytime due to increased detection noise from sunlight. To circumvent this problem, we propose a free-space link based on entangled photon pairs with a wavelength of 589 nm. This wavelength coincides with the sodium D_2 line which is one of the most prominent Fraunhofer lines. Hence during daytime, the reduced amount of sunlight at this wavelength should allow for an improved transmission rate. Our research project includes the creation of entangled photon pairs at 589 nm, setting up a free-space link over several kilometers using telescopes, and demonstrating quantum key distribution using the BBM92 protocol. We report on our latest progress.

Q 31.2 Wed 11:15 HS 3219

A scalable quantum register for multiplexed atom-photon entanglement — •Lukas Hartung[1], Matthias Seubert[1], Stephan Welte[2], Emanuele Distante[1], and Gerhard Rempe[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching — [2]ETH Zürich, Otto-Stern-Weg 1, 8093 Zürich

Trapped atoms in the centre of a cavity have been used for the efficient generation of atom-photon entanglement[1]. However, in past experiments the number of atoms in the resonator was limited to at most two[2], as the loading of individual atoms was based on probabilistic schemes. To overcome this limitation, we have extended our setup with an addressing system that allows to load presently up to six atoms into the cavity using optical tweezers. Additionally, the system enables individual addressing of the atoms to generate atom-photon entangled pairs via a vaccum STIRAP[3]. We show that the fidelity of this entanglement process is independent of the number and spatial arrangement of the atoms, which is an indicator of the scalability of our system. Finally, we use the setup to generate atom-photon entanglement in a multiplexed way with an efficiency of up to 88.6(1)%.

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

[2] Stephan Welte et al., Photon-Mediated Quantum Gate between Two Neutral Atoms in an Optical Cavity, Phys. Rev. X 8, 011-018 (2018).

[3] Tatjana Wilk et al., Single-Atom Single-Photon Quantum Interface. Science 317, 488-490 (2007).

Q 31.3 Wed 11:30 HS 3219

Towards time-energy entanglement swapping of asynchronous sources — •Karen Lozano-Mendez[1,2], Markus Leipe[1,2], Sakshi Sharma[1,2], Meritxell Cabrejo Ponce[1,2], and Fabian Steinlechner[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [2]Friedrich Schiller University Jena, Institute of Applied Physics, Abbe Center of Photonics, Albert-Einstein-Str. 15, 07745 Jena, Germany

Time-energy entanglement in photons is a robust choice for fiber-based quantum communications. Entanglement can be 'swapped' if two independent entangled photons pairs are prepared and a Bell state measurement is made between two photons, one from each source. This will project the two remaining, non-interacting photons in an entangled state. Entanglement swapping has been successfully executed using synchronized, pulse-pumped sources. However, only a few realizations using a continuous wave pump have been reported.

We use entangled photon pairs generated independently via SPDC from two integrated ppLN waveguides, which are pumped by a 775nm CW laser. The down converted photons have a center wavelength of 1550 nm and are further filtered using Fiber Bragg Gratings with 45pm bandwidth at the wavelengths of 1530 nm (signal) and 1570 nm (idler) for each pair. The signal photons interfere in a beam splitter and the four-fold coincidence rate is measured using a time-tagging device, yielding over 150 counts per hour.

The present work is the first step towards high-efficient time-energy entanglement swapping between asynchronous sources.

Q 31.4 Wed 11:45 HS 3219

Experimental boosted linear-optical Bell-state measurement — •Nico Hauser, Matthias Bayerbach, Simone D'Aurelio, and Stefanie Barz — Universität Stuttgart, Institut für funktionelle Materie und Quantentechnologien

Bell-state measurements are integral to many quantum communication and computation protocols. The conventional scheme for a linear-optical Bell-state measurement provides only a definite identification for two out of the four Bell states, resulting in an overall efficiency of 50%. Here we implement a scheme that significantly increases this efficiency by using an entangled ancillary photon pair and a fibre-based balanced 4x4 splitter. Using this scheme, we achieve a significant increase of the Bell-state measurement efficiency compared to the standard scheme.

Q 31.5 Wed 12:00 HS 3219

Quantum communication protocols over the 14-km Saarbrücken fiber link — •Christian Haen, Stephan Kucera, Elena Arensktötter, Jonas Meiers, Tobias Bauer, and Jürgen Eschner — Universität des Saarlandes, Saarbrücken, Deutschland

Existing telecom-fiber infrastructure provides the basis for creating large scale quantum networks, potentially leading to the implementation of a quantum internet. The deployment of glassfibers for this purpose poses certain challenges, especially in urban areas, such as large disturbances in polarization.

We report on a 14-km long dark fiber link running across the Saarbrücken urban area, which we characterize for quantum networking by transmission of polarization- or time-bin-encoded photonic quantum bits. We stabilize the polarization of the fiber link and demonstrate quantum networking operations using a 40Ca+ single-ion quantum memory, an ion-resonant entangled photon-pair source, and quantum frequency conversion from the atomic wavelength to the telecom C-band. We realize dual-wavelength photon-photon entanglement, entanglement between an ion and a telecom photon, and teleportation of a qubit state from the ion onto a telecom photon transmitted over the link.

Q 31.6 Wed 12:15 HS 3219

Towards polarization entanglement distribution in a metropolitan dark-fibre network in Berlin — •William Staunton[1], Sebastian Brauner[2], Kai-Hong Luo[2], Harald Herrmann[2], and Oliver Benson[1] — [1]Humboldt University, Berlin, Germany — [2]Paderborn University, Paderborn, Germany

Efficient distribution of entanglement is essential in the potential realization of a quantum internet[1]. Thanks to the maturity of the classical telecommunications industry, a worldwide network of single-mode optical optical fibres is already in existence. With such an infrastructure and quantum repeater functionalities we could move towards distributed quantum computation and quantum communication on a global scale. We present the work towards polarization entanglement distribution in a metropolitan, field-installed dark-fibre network in Berlin. With focus on results of the active polarization stabilization employed. We also introduce the novel, degenerate, resonant, type-II periodically poled Lithium Niobate (PPLN) spontaneous parametric down-conversion (SPDC) waveguide source[2] producing entangled photon pairs with high brightness and narrow linewidth. Crucially, such sources emit photons with pure spectral states. With an emission bandwidth optimized for interacting with quantum memories, we show how the source is optimized for quantum repeater demonstrations. [1] Kimble, H. J. (2008). The quantum internet. Nature, 453(7198), 1023*1030. [2] K.-H. Luo et al., Phys. Rev. Lett. 115, 200401 (2015).

Q 31.7 Wed 12:30 HS 3219

Deployment and optimization of high-dimensional QKD on a 1.7 km free-space link — •Karolina Paciorek[1], Christopher Spiess[1,2], Sarika Mishra[1], and Fabian Steinlechner[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Strasse 7, Jena 07745, Germany — [2]Friedrich Schiller University, Institute of Applied Physics, Abbe Center of Photonics, Albert-Einstein-Strasse 15, Jena 07745, Germany

Quantum Key Distribution (QKD) is a method for establishing a secure encryption key using a quantum optical sender, a transmission link, and an optical receiver. When QKD is implemented over short distances with low losses, such as in data centers or intercity links, then the maximum secure key rate is typically limited by saturation of the single-photon detectors at the receiver. To overcome this limitation, high-dimensional QKD protocols can be implemented.

High-dimensional QKD protocols enable encoding more information into one photon, which enables operation at photon rates that no longer saturate the detectors. We show this at the example of a weak coherent source in a time-phase encoding scheme. Furthermore, we demonstrate the transfer of key material over a 1.7 km intercity free-space link. Our demonstration is accompanied by finite-key analysis together with an extensive parameter optimization in experiment and simulations to maximize the key rate. Our results show that high-dimensional QKD with weak coherent sources is a promising avenue towards versatile communication scenarios, including areas with difficult access such as rapidly changing metropolitan spaces or in satellite communication.

Q 31.8 Wed 12:45 HS 3219

A quantum frequency converter for entanglement distribution across a metropolitan network — •Maya Büki, Gianvito Chiarella, Tobias Frank, Pau Farrerra, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institute for Quantum Optics, Garching, Germany

Single atoms in a cavity serve as a suitable building block for quantum networks as cavities offer an ideal interface between light and matter qubits in terms of both efficiency and fidelity. Within this scope, we can efficiently entangle the spin states of Rubidium (Rb) atoms with optical polarization qubits. Despite offering numerous capabilities for quantum networks, such as being a source of (complex) atom-photon entanglement, enabling heralding quantum memories, and facilitating quantum repeaters, there is a drawback when aiming for long-distance quantum networks, and that is the wavelength of the optical qubit at $\lambda_{\mathrm{Rb}} = 780$ nm, causing intrinsic fiber losses to be quite high.

To circumvent these losses, a quantum frequency conversion to the telecom regime becomes necessary. Here, we demonstrate a quantum frequency converter (QFC) that exhibits a good efficiency and high signal-to-noise ratio. Alongside a narrow filtering system this QFC will be employed to connect two quantum nodes through 23km of optical fiber across the metropolitan area of Munich. We will present preliminary results about this fiber channel outside the lab, with the prospect of distributing entanglement across a real world quantum network link.

Q 32: Fermionic Quantum Gases II (joint session Q/A)

Time: Wednesday 14:30–16:30 Location: Aula

Q 32.1 Wed 14:30 Aula

Exact one-particle density matrix for SU(N) fermionic matter-waves in the strong repulsive limit — •Andreas Osterloh[1], Wayne Chetcuti[1], Juan Polo[1], and Luigi Amico[1,2] — [1]Technology Innovation Institute, Masdar City and Yas Island, P.O. box 9639Abu Dhabi, UAE — [2]Dipartimento di Fisica e Astronomia Ettore Majorana, Via S. Sofia 64, 95127 Catania, Italy

We consider a gas of repulsive N-component fermions confined in a ring-shaped potential, subject to an effective magnetic field. For large repulsion strengths, we work out a Bethe ansatz scheme to compute the two-point correlation matrix and then the one-particle density matrix. Our results holds in the mesoscopic regime of finite but sufficiently large number of particles and system size that are not accessible by numerics. We access the momentum distribution of the system and analyse its specific dependence of interaction, magnetic field and number of components N. In the context of cold atoms, the exact computation of the correlation matrix to determine the interference patterns that are produced by releasing cold atoms from ring traps is carried out.

Q 32.2 Wed 14:45 Aula

Universal Entropy Transport in Fermionic Superfluids across the BEC-BCS Crossover — Jeffrey Mohan, •Simon Wili, Philipp Fabritius, Mohsen Talebi, Meng-Zi Huang, and Tilman Esslinger — ETH Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

Particle transport between two superfluids is often associated with reversible, entropy-free supercurrents, such as in the Josephson and fountain effects. However, this only applies to weakly-coupled superfluids in the linear response regime. Here, we experimentally investigate particle and entropy flow within a ballistic channel, strongly coupling two superfluids across the BEC-BCS crossover. Our observations reveal large currents of both particles and entropy. While these currents depend on the channel's geometry, the entropy transported per particle appears constant across different geometries. Instead, it is influenced by the interaction strength and reservoir degeneracy. This suggests that the non-equilibrium currents flowing through the channel inherit the universal equilibrium properties from the reservoirs. Moreover, when distinguishing advective and diffusive entropy currents, we find that the Wiedemann Franz law, which describes the relation of these currents in Fermi liquids, is strongly violated at unitarity but partially restored on the BCS side. The present observations raise fundamental questions about transport in strongly interacting, non-equilibrium Fermi systems.

Q 32.3 Wed 15:00 Aula

Unravelling Interaction and Temperature Contributions in Unpolarized Trapped Fermionic Atoms in the BCS Regime — •Sejung Yong, Sian Barbosa, Jennifer Koch, Felix Lang, Axel Pelster, and Artur Widera — Physics Department and Research Center OPTIMAS, Kaiserslautern-Landau, Germany

In the BCS limit density profiles for unpolarized trapped fermionic clouds of atoms are largely featureless. Therefore, it is a delicate task to analyze them in order to quantify their respective interaction and temperature contributions. Temperature measurements have so far been mostly considered in an indirect way, where one sweeps isentropically from the BCS to the BEC limit. Instead we suggest here a direct thermometry, which relies on measuring the column density and comparing the obtained data with a Hartree-Bogoliubov mean-field theory combined with a local density approximation. In case of an attractive interaction between two-components of ^{6}Li atoms trapped in a tri-axial harmonic confinement we show that minimizing the error within such an experiment-theory collaboration turns out to be a reasonable criterion for analyzing in detail measured densities and, thus, for ultimately determining the sample temperatures. The findings are discussed in view of various possible sources of errors.

[1] S. Yong, S. Barbosa, J. Koch, F. Lang, A. Pelster, and A. Widera, arXiv:2311.08853

Q 32.4 Wed 15:15 Aula

A quantum engine in the BEC-BCS crossover — •Jennifer Koch[1], Keerthy Menon[2], Eloisa Cuestas[2,3], Sian Barbosa[1], Eric Lutz[4], Thomás Fogarty[2], Thomas Busch[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]OIST Graduate University, Onna, Japan — [3]Enrique Gaviola Institute of Physics, Córdoba, Argentina — [4]Institute for Theoretical Physics I, University of Stuttgart, Germany

Heat engines convert thermal energy into mechanical work both in the classical and quantum regimes. However, quantum theory offers genuine nonclassical forms of energy, different from heat, which so far have not been exploited in cyclic engines to produce useful work. In this talk, I will discuss a recently realized quantum many-body engine fuelled by the energy difference between fermionic and bosonic ensembles of ultracold particles that follows from the Pauli exclusion principle [1]. We employ a harmonically trapped superfluid gas of ^{6}Li atoms close to a magnetic Feshbach resonance, which allows us to effectively change the quantum statistics from Bose-Einstein to Fermi-Dirac by tuning the gas between a Bose-Einstein condensate of bosonic molecules and a unitary Fermi gas (and back) through a magnetic field. The talk will focus on the quantum nature of such a Pauli engine. Additionally, I will present the pressure-volume diagram of the new kind of engine and show how the engine behaves after multiple cycles. Our findings establish quantum statistics as a useful thermodynamic resource for work production. [1] J. Koch et al., Nature 621, 723 (2023)

Q 32.5 Wed 15:30 Aula

A generalized formalism to describe multi-channel Hartree-Fock-Bogoliubov interactions in fermionic systems — •Nikolai Kaschewski[1], Axel Pelster[1], and Carlos A. R. Sá de Melo[2] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]School of Physics, Georgia Institute of Technology, Atlanta, USA

A simplified description of fermionic systems relies on the Hartree-Fock-Bogoliubov (HFB) approximation, where the interaction is decomposed into distinct channels. However, an major issue with this procedure is that the separation between the channels is somewhat arbitrary. In some cases, only one interaction channel is considered, e.g the pairing channel in the BCS theory and the BCS-BEC crossover, or in other cases, two different interaction channels are artificially separated like in the Jellium model. In this talk, we present a generalized self-consistent theory by using weighting parameters for each channel. Our approach removes the arbitrariness of channel separation and provides a minimization principle for the optimal partitioning. We present this formalism for any type of spatially non local potentials without memory and derive the respective HFB self-consistency equations on a mean-field level and show how inter-channel interactions arise. We illustrate the power of our technique with a simple example before showing on a formal level how to include pairing, density, and exchange fluctuations simultaneously without miscounting or double-counting states.

Q 32.6 Wed 15:45 Aula

The role of particle-hole interactions and effective ranges in homogeneous Fermi fluids — Nikolai Kaschewski[1], Axel Pelster[1], and •Carlos A. R. Sá de Melo[2] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]School of Physics, Georgia Institute of Technology, Atlanta, USA

The standard theoretical method for studying fermionic superfluidity is based on the description of interactions in terms of pairing and on the identification of a superfluid order parameter. Only particle-particle (pp) processes are included that form Cooper pairs which then perform Bose-Einstein condensation. Particle-hole (ph) processes are only sparsely considered. One example are the ph fluctuations of Gor'kov and Melik-Barkhudarov that lowers the condensation temperature [1]. On this poster, we present a self-consistent mean-field theory for BCS superfluidity that includes pp and ph processes simultaneously through a weighted partitioning of states that produce and inhibit pairing. We obtain non-perturbative corrections due to ph scattering, which require an effective range expansion [2] in order to get physical results. The theory generalizes the BCS mean field theory, makes connections to effective-range mean-field effects [3]. Our preliminary results set the stage for the simultaneous exploration of fluctuations in the pp and ph channels [1] in the BCS-BEC crossover.

[1] L.P. Gor'kov, T.K. Melik-Barkhudarov, Sov. Phys. JETP **13**, 1018 (1961) [2] H. A. Bethe, Phys. Rev. **76**, 38 (1949) [3] S. Mal and B. Deb, J. of Phys. B **55**, 035301 (2022)

Q 32.7 Wed 16:00 Aula

Topological pumping induced by interactions — konrad viebahn[1], anne-sophie walter[1], eric bertok[2], •zijie zhu[1], marius gächter[1], armando a. aligia[3], fabian heidrich-meisner[2], and tilman esslinger[1] — [1]Institute for Quantum Electronics & Quantum Center, ETH Zurich, 8093 Zurich, Switzerland — [2]Institute for Theoretical Physics, Georg-August-Universität Göttingen, 37077 Göttingen, Germany — [3]Instituto de Nanociencia y Nanotecnologia CNEA-CONICET, Centro Atomico Bariloche and Instituto Balseiro, 8400 Bariloche, Argentina

A topological 'Thouless' pump represents the quantised motion of particles in response to a slow, cyclic modulation of external control parameters. The Thouless pump, like the quantum Hall effect, is of fundamental interest because it links physically measurable quantities, such as particle currents, to geometric properties which can be robust against perturbations and thus technologically useful. Here we observe a Thouless-type charge pump in which the particle current and its directionality inherently rely on the presence of strong interactions. Experimentally, we utilise fermionic atoms in a dynamical superlattice which traces a pump trajectory that remains trivial in the non-interacting limit. Remarkably, the transferred charge in the interacting system is half of its usual value in the non-interacting case, in agreement with matrix-product-state simulations. Our experiments suggest that Thouless charge pumps are promising platforms to gain insights into interaction-driven topological transitions and topological quantum matter.

Q 32.8 Wed 16:15 Aula

Kapitza-Dirac scattering of strongly interacting Fermi gases — •Max Hachmann[1], Yann Kiefer[1,2], and Andreas Hemmerich[1] — [1]Universität Hamburg, Hamburg, Deutschland — [2]ETH, Zürich, Schweiz

We experimentally probe properties of interacting spin-mixtures of fermionic (40K) atoms by studying their interaction with light. An elementary scattering scenario is resonant Bragg diffraction, also referred to as Bragg spectroscopy, where matter is diffracted from a onedimensional (1D) optical standing wave. A Feshbach resonance is used to tune the interactions across the entire BEC-BCS crossover regime, including the point of unitarity. With the preparation schemes available in our experiment, the scattering lengths can be dynamically tuned, such that either repulsively bound molecular dimers (Feshbach molecules) or pairs of unbound fermions can be studied. To benchmark our scattering protocol, we apply it to a sample of spin-polarized non-interacting fermionic atoms and study the dynamical behaviour. In this case, a simple model using a time-dependent Schrödinger equation yields surprisingly accurate results, well matching the experimental observations. For spin-mixtures in the unitarity regime, the higher order diffraction peaks are observed to disappear with no conclusive theoretical description presently available.

Q 33: Open Quantum Systems

Time: Wednesday 14:30–16:30 Location: HS 1199

Q 33.1 Wed 14:30 HS 1199

Multimode-cavity picture of non-Markovian waveguide QED — Luca Ferialdi[1], •Dario Cilluffo[2], G. Massimo Palma[1,3], Giuseppe Calajò[4], and Francesco Ciccarello[1,3] — [1]Università degli Studi di Palermo, Dipartimento di Fisica e Chimica Emilio Segrè, via Archirafi 36, I-90123 Palermo, Italy — [2]Institut für Theoretische Physik and IQST, Albert-Einstein-Allee 11, Universität Ulm, 89069 Ulm, Germany — [3]NEST, Istituto Nanoscienze-CNR, Piazza S. Silvestro 12, 56127 Pisa, Italy — [4]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Padova, I-35131 Padova, Italy

We introduce a picture to describe and intrepret waveguide-QED problems in the non-Markovian regime of long photonic retardation times (resulting in delayed coherent feedback). The framework is based on an intuitive spatial decomposition of the waveguide into blocks. Among these, the block directly coupled to the atoms embodies an effective lossy multimode cavity leaking into the rest of the waveguide (in turn embodying an effective white-noise bath). The dynamics can be approximated by retaining only a finite number of cavity modes that yet eventually grows with the time delay. The picture allows to explicitly connect emission properties subject to feedback to the standard Purcell effect in a cavity, both in the usual bad-cavity limit and beyond, thus providing an explicit link between waveguide QED and cavity QED.

Q 33.2 Wed 14:45 HS 1199

Landau-Zener dynamics in the presence of a non-Markovian reservoir — •Raphaël Menu and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

We analyse the Landau-Zener dynamics of a qubit, which is simultaneously coupled to a dissipative auxiliary system. By tuning the coupling, the qubit dynamics ranges from a dephasing master equation to a strongly coupled qubit-auxiliary system, which is effectively a non-Markovian reservoir for the qubit. We determine the quantum trajectories in the different regimes . For each regime we analyse the distribution of each trajectory in terms of the time-dependent probability of a diabatic transitio. Depending on the strength of the coupling, we observe multipeaked configurations, which undergo transitions to narrow distributions. These transitions are signalled by a higher probability that a jump occurs. The behavior of the probability of a quantum jump as a function of the coupling and of the time of the sweep, in turn, allows us to shed light on the stages of the dynamics when the environment is detrimental and when instead it corrects diabatic transition. It shows, in particular, that memory effects can be beneficial. It further sheds light on the role of pausing in annealing and when it is advantageous.

Q 33.3 Wed 15:00 HS 1199

Dynamically Emergent Quantum Thermodynamics: The Non-Markovian Otto Cycle — •Irene Ada Picatoste[1], Alessandra Colla[1], and Heinz-Peter Breuer[1,2] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Using an open-system approach to quantum thermodynamics at arbitrary coupling [1] we study the Otto cycle in the strong-coupling and non-Markovian regimes [2]. Our investigation is based on the exact treatment of the dynamics of the system when coupled to a thermal reservoir, which we describe employing the Fano-Anderson model. We study the effects of strong coupling and a structured environment, and find that a non-Markovian bath can exchange both heat and work with the system. We identify a regime of enhanced efficiency occurring when the peak of the spectral density is located within the frequency range of the cycle, and explain this through an analysis of the renormalized frequencies emerging from the system-bath interaction.

[1] A. Colla and H.-P. Breuer, Open-system approach to nonequilibrium quantum thermodynamics at arbitrary coupling, May 2022, 10.1103/PhysRevA.105.052216.

[2] I. A. Picatoste, A. Colla and H.-P. Breuer, Dynamically Emergent Quantum Thermodynamics: Non-Markovian Otto Cycle, Aug 2022, axXiv: 2308.09462 [quant-ph].

Q 33.4 Wed 15:15 HS 1199

Thermodynamic behaviour of giant artificial atoms with non-Markovian thermalization — •Mei Yu, H. Chau Nguyen, and Stefan Nimmrichter — University of Siegen, Siegen, Germany

Superconducting qubits, when coupled to either a meandering transmission line or to surface acoustic waves, enable the creation of giant artificial atoms. These artificial atoms, if connected to a waveguide through multiple separated contacts, can be made to interact with a travelling bosonic field at multiple points in time. This results in a tailored memory effect and non-Markovian dynamics that has been demonstrated experimentally [1]. We investigate scenarios in which one or more giant atoms couple to thermally excited waveguide radiation via multiple contacts, leading to non-Markovian equilibration processes. We then apply such setups in case studies of non-Markovian heat transport and refrigeration between independent thermal reservoirs

[1] G. Andersson, B. Suri, L. Guo, T. Aref, and P. Delsing, Non-exponential decay of a giant artificial atom, Nature Physics 15, 1123 (2019).

Q 33.5 Wed 15:30 HS 1199

Thermodynamic role of general environments: from heat bath to work reservoir — •Alessandra Colla and Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Environments in quantum thermodynamics usually take the role of heat baths. These baths are Markovian, weakly coupled to the system, and initialized in a thermal state. Whenever one of these properties is missing, standard quantum thermodynamics is no longer suitable to treat the thermodynamic properties of the system that result from the interaction with the environment. Using a recently proposed framework for open system quantum thermodynamics at arbitrary coupling regimes [1], we show that within the very same model (a Fano-Anderson Hamiltonian) the environment can take three different thermodynamic roles: a standard heat bath, exchanging only heat with the system, a work reservoir, exchanging only work, and a hybrid environment, providing both types of energy exchange. The exact role of the environment is determined by the strength and structure of the coupling, and by its initial state.

[1] A. Colla, H.-P. Breuer, Physical Review A 105, 052216 (2022)

Q 33.6 Wed 15:45 HS 1199

non-Markovian processes might behave like Markov processes — •bilal cantürk and heinz-peter breuer — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

The Chapman-Kolmogorov equation is generally considered to be the main characteristic of Markov processes. However, we have shown by construction that there are also non-Markovian processes that satisfy the Chapman-Kolmogorov equation. This evidence allows us to further clarify the distinction between Markov and non-Markovian processes in both classical and quantum systems. In addition, our results allow us to construct some specific non-Markovian processes, called P-divisible processes.

Q 33.7 Wed 16:00 HS 1199

Characterizing the time dependence of quantum gates — Alessio Belenchia[1], Daniel Braun[1], Giovanni Gramegna[2], and •Stanislaw Soltan[1] — [1]Eberhard Karls Universität Tübingen, Tübingen, Deutschland — [2]Università degli Studi di Bari Aldo Moro, Bari, Italien

Current state-of-the-art quantum computers exhibit some non-markovian memory effects that make the actual quantum gates deviate from the ideal case. Characterization of such errors is an ongoing challenge. Successfully addressing this challenge could enable the correction of errors or, alternatively, harness these effects to enhance the control of qubits' states and for dissipative-based computation. We analyze the possible generalization of long sequence gate set tomography that takes into account the possible time dependence of quantum gates. A form of time dependence must be assumed and we derived it from the post-markovian master equation. The time dependence of the gates is taken to be explicit in the case of the simplest models of the memory effects. For more complex ones, it is reformulated as the time-independent interaction between the system of interest and auxiliary virtual qubits.

Q 33.8 Wed 16:15 HS 1199

Stochastic unraveling of pseudo-Lindblad equations — •Tobias Becker and André Eckardt — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany

For the efficient simulation of open quantum systems we often use quantum jump trajectories given by pure states that evolve stochastically to unravel the dynamics of the underlying master equation. In the Markovian regime, when the dynamics is described by a Gorini-Kossakowski-Sudarshan-Lindblad (GKSL) master equation, this procedure is known as Monte Carlo wave function (MCWF) approach. However, beyond ultraweak system-bath coupling, the dynamics of the system is not described by an equation of GKSL type, but rather by the Redfield equation, which can be brought into pseudo-Lindblad form. Here negative dissipation strengths prohibit the conventional approach. To overcome this problem, we propose a pseudo-Lindblad quantum trajectory (PLQT) unraveling. It does not require an effective extension of the state space, like other approaches, except for the addition of a single classical bit.

Q 34: Color Centers II

Time: Wednesday 14:30–16:15 Location: HS 1221

Invited Talk Q 34.1 Wed 14:30 HS 1221

Optically addressable nuclear spin registers with V2 center in 4H-SiC — •Vadim Vorobev — University of Stuttgart, Stuttgart, Germany

The V2 center is a promising platform for spin photon interface, with tolerable optical coherent properties in nanostructures with up to 20K temperature working conditions.

This becomes handy with extensive microwave and radiofrequency-based manipulation methods for controlling the nuclear spins.

The current progress with the detection of up to 5 nuclear spins and extensive characterization of their hyperfine tensor and control parameters will be presented. Finally, an outlook of potential ways to improve the technology will be presented.

Q 34.2 Wed 15:00 HS 1221

Implementation of the SUPER coherent control scheme with a tin-vacancy color center in diamond — •Mustafa Gökçe[1], Cem Güney Torun[1], Thomas K. Bracht[2], Mariano Isaza Monsalve[1], Sarah Benbouabdellah[1], Özgür Ozan Nacitarhan[1], Marco E. Stucki[1,3], Gregor Pieplow[1], Tommaso Pregnolato[1,3], Joseph H. D. Munns[1], Doris E. Reiter[4], and Tim Schröder[1,3] — [1]Humboldt University of Berlin, Berlin, Germany — [2]University of Münster, Münster, Germany — [3]Ferdinand-Braun-Institute, 12489 Berlin, Germany — [4]Technical University Dortmund, Dortmund, Germany

The creation of coherent single photons for quantum applications requires deterministic excitation, realized by resonant excitation. However, a challenge is filtering spectrally overlapping the excitation laser from emitted single photons. One method for separation is using cross-polarization microscopy, which results in 50% loss of emitted photons. A novel method of coherent excitation called the swing-up of the quantum emitter population (SUPER) has been introduced. This method incorporates two-color nonresonant pulses achieving full inversion to the excited state. The SUPER method enables spectral filtering. To implement the SUPER method, we built a spectral pulse engineering setup, which tailors pulses with desired spectral shapes. We demonstrate coherent single photon emission using non resonant pulses and replicate our results using a theoretical model. We employ this method using pulses in the picosecond pulse duration regime and pave the way for utilization of these gates for the investigation of ultrafast processes.

Q 34.3 Wed 15:15 HS 1221

Color centers in silicon carbide integrated into a fiber-based Fabry-Pérot microcavity — •Jannis Hessenauer[1], Jonathan Körber[2], Maximilian Pallmann[1], Jawad Ul-Hassan[3], Georgy Astakhov[4], Florian Kaiser[5], Jörg Wrachtrup[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Germany — [2]3rd Institute of Physics, University of Stuttgart, Germany — [3]Department of Physics, Chemistry and Biology, Linköping University, Sweden — [4]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Dresden, Germany — [5]MRT Department, Luxembourg Institute of Science and Technology & Department of Physics and Materials Science, University of Luxembourg, Belvaux, Luxembourg

Color centers in silicon carbide (SiC) have recently emerged as promising solid-state spin-photon interfaces. Among those, the two negatively charged silicon vacancy centers in 4H-SiC have been studied extensively, and showed narrow optical linewidths close to the lifetime limit. In this work, we integrate a few micron-thick SiC membrane with color centers into a cryogenic fiber-based Fabry-Pérot-resonator. We characterize the cavity performance and observe a high finesse, indicating low losses introduced by the membrane. We study the complex mode dispersion stemming from the hybridization of the membrane with the empty cavity and the strong birefringence of the material. Finally, we observe cavity-coupled emission of color centers by tuning the cavity resonance over a spectral region while monitoring the fluorescence.

Q 34.4 Wed 15:30 HS 1221

Quantum Non-linear Optics with Diamond Color Centers in Fiber-based Microcavities — •Julius Fischer[1], Yanik Herrmann[1], Julia M. Brevoord[1], Colin Sauerzapf[1], Leonardo G. C. Wienhoven[1], Laurens J. Feije[1], Matteo Pasini[1], Martin Eschen[1,2], Maximilian Ruf[1], Matthew J. Weaver[1], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2628 CJ Delft, The Netherlands — [2]Netherlands Organisation for Applied Scientific Research (TNO), P.O. Box 155, 2600 AD Delft, The Netherlands

Quantum networks are promising for applications such as secure communication and distributed quantum computing. Diamond color center qubits like the Tin-Vacancy (SnV) center are excellent node candidates, but they have limited collectable coherent photon emission. Integration into a tunable, open microcavity can boost collection and coherent emission via the Purcell effect. We report on our results of coupling individual SnV centers to the microcavity. We achieve significant Purcell-enhancement, evidenced through lifetime reduction and linewidth broadening and demonstrate the first SnV-induced cavity transmission dip, which reaches 50 % on resonance. This effect is characterized depending on cavity detuning and probe power, and we show bunching in the photon statistics of the transmitted light. A detailed quantum optical model is used to explain the data. These results outline a key element for cavity quantum optics experiments and for efficient spin-photon interfaces.

Q 34.5 Wed 15:45 HS 1221

Heralded initialization of charge state and optical transition frequency of diamond tin-vacancy centers — •Julia Maria Brevoord, Lorenzo De Santis, Takashi Yamamoto, Matteo Pasini, Nina Codreanu, Tim Turan, Hans Beukers, Christopher Waas, and Ronald Hanson — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands

Diamond Tin-Vacancy centers have emerged as a promising platform for quantum information science and technology. A key challenge for their use in more complex quantum experiments and scalable applications is the ability to prepare the center in the desired charge state with the optical transition at a pre-defined frequency. Here we report on heralding such successful preparation using a combination of laser excitation, photon detection, and real-time logic. We verify the power of this method by measuring strongly improved quantum optical performance, showing its direct relevance for future quantum applications that rely on photon interference such as remote entanglement generation.

Q 34.6 Wed 16:00 HS 1221

Electron-Phonon Coupling of Mechanically Isolated Defect Centers in Hexagonal Boron Nitride — •Patrick Maier, Michael Koch, and Michael Höse — Universität Ulm

Single Photon emitters are a crucial resource for novel quantum optic technologies. Hosted quantum emitters in hexagonal Boron Nitride (hBN) are promising candidates for the integration into hybrid quantum systems, which can be used in upcoming quantum optic technologies. One type of such emitter has shown the remarkable property of Fourier transform limited optical linewidth at cryogenic temperatures and even up to room temperature. [1,2]. This characteristic can be traced back to out-of-plane emitters, which do not couple to in-plane phonon modes. That leads to mechanical isolation of the defect centers orbitals [3]. Here, we present our most recent results towards understanding the origin of this mechanical decoupling.

[1] A. Dietrich et al., Physical Review B, Vol. 98 (2018) [2] A. Dietrich et al., Physical Review B, Vol. 101 (2020) [3] M. Hoese et al., Science Advances, Vol. 6 (2020)

Q 35: Quantum States of Light

Time: Wednesday 14:30–16:30 Location: HS 3118

Invited Talk Q 35.1 Wed 14:30 HS 3118

Quantum correlations in the phase space — Martin Bohmann[1], Jan Sperling[2], Nicola Biagi[3,5], Alessandro Zavatta[3,4], Marco Bellini[3,5], and •Elizabeth Agudelo[6] — [1]Quantum Technology Laboratories GmbH, 1100 Vienna, Austria — [2]PhoQS, Paderborn University, 33098 Paderborn, Germany — [3]CNR-INO, 50125 Florence, Italy — [4]QTI S.r.l., 50125 Florence, Italy — [5]LENS and Department of Physics and Astronomy, University of Firenze, 50019 Florence, Italy — [6]TU Wien, Atominstitut, 1020 Vienna, Austria

Today, we are utilizing quantum physics to propel advancements in quantum information science and technology, yet there remain unanswered fundamental inquiries about the nature of quantum and its ability to exceed classical boundaries. Our strategy includes characterizing physical systems within phase space. In my presentation, I will examine the boundary between quantum and classical realms, introducing innovative, mathematically robust techniques for practical applications. These methods offer distinct insights into what differentiates the classical world from the quantum domain, and also facilitate the characterization of quantum states of light. For instance, we will confirm effects that surpass classical correlations using a theory that is friendly to experimental settings. We will showcase cutting-edge techniques for differentiating between classical and quantum phenomena that coexist in quantum optics experiments. This involves introducing concepts like nonclassicality quasiprobabilities and phase space inequalities, and investigating quantum effects in correlated systems, including hybrid systems.

Q 35.2 Wed 15:00 HS 3118

Quantum and Classical Information Flow in Phase Space — •Moritz F. Richter and Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Germany

Exchange of information between an open quantum system and its environment, especially the backflow of information to the system associated with quantum notions of non-Markovianity, is a widely discussed topic for years now [1]. Usually the information flow is quantified by the increase of suitable distance measures between two initial states of the open quantum system at hand. However, the same idea can also be used to identify information backflow in classical systems and their dynamics in phase space. In the talk we will address how information backflow of a continuous variable (CV) quantum system can be quantified by means of its phase space representation - i.e. quasi-probability distributions - and how this leads to a notion of non-Markovianity using distance measures between probability distributions representing classical states in phase space [2]. [1] Breuer H-P, Laine E-M, Piilo J and Vacchini B; 2016 "Colloquium: non-Markovian dynamics in open quantum systems"; Rev. Mod. Phys. 88 021002

[2] Richter M F, Wiedemann R and Breuer H-P; 2022 "Witnessing non-Markovianity by quantum quasi- probability distributions"; New J. Phys. 24 123022

Q 35.3 Wed 15:15 HS 3118

Towards Large Schrödinger Cat States with Optical Photons — •Hendrik Hegels, Michael Eichenberger, Stephan Dürr, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Large Schrödinger cat states allow probing the border between quantum physics and classical physics. At the same time, they provide a valuable resource for continuous variable quantum computing, quantum communication and quantum error correction schemes. In practice these applications require Schrödinger cat states with mean photon number $\gtrsim 4$. There are several experimental demonstrations of optical cat states, but so far none could reach or even surpass this limit. Here, we present an apparatus based on Rydberg-EIT in an atomic ensemble in an optical cavity that has the potential to overcome this limit and produce large optical cat states for the first time.

Q 35.4 Wed 15:30 HS 3118

Tailoring the sensitivity of gravitational-wave detectors to neutron star merger signals with internal squeezing — •Niels Böttner, Mikhail Korobko, Joe Bentley, and Roman Schnabel — Institut für Quantenphysik und Zentrum für Optische Quantentechnologien der Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

The observation of gravitational waves from binary neutron star mergers is an excellent opportunity to study them and their fundamental properties. During the late inspiral, gravitational waves in the kilohertz-band are generated that contain information about nuclear matter at extreme densities. However, current gravitational-wave observatories are not sensitive enough to detect these gravitational waves because they are limited by quantum noise. Here, we propose to flexibly tune the sensitivity in the kilohertz-band with a new concept called Twin Recycling Quantum Expander. The design of this concept corresponds to a dual-recycled Fabry-Pèrot-Michelson interferometer that we customized by adding a second recycling cavity to it and by placing a nonlinear crystal inside the signal recycling cavity to generate squeezed states of light. The coupled cavity structure and the generated squeezing improve the signal-to-noise ratio at high frequencies. We demonstrate that our new concept allows us to increase and tune the sensitivity in the kilohertz-band, bringing the additional level of flexibility and enhancement to the existing concepts of future detectors. We anticipate our results to be a valuable new approach for the design of future gravitational wave detectors.

Q 35.5 Wed 15:45 HS 3118

Photon Bose–Einstein Condensate in a Planar Cavity in the Thermodynamic Limit — •Andris Erglis[1] and Stefan Yoshi Buhmann[2] — [1]University of Freiburg, Freiburg, Germany — [2]University of Kassel, Kassel, Germany

It has been of general interest to explore the different behaviour of a Bose–Einstein condensate (BEC) for finite versus infinite systems. For instance, the critical number of particles in two dimensions diverges in the thermodynamic limit, while being well-defined for a system of finite size.

We are investigating the photon BEC inside a two dimensional planar cavity at the crossover between finite and infinite size, where our control parameter is the transversal mode spacing. In addition to the usual primary condensation threshold, we observe arrested condensation and an emergence of a second critical threshold proportional to the mode spacing, where the condensate is forming. This result, which we have derived using an analytical two-mode solutions, is corroborated by numerical simulations for larger mode numbers.

Q 35.6 Wed 16:00 HS 3118

Creation of Non-Gaussian Quantum States with a GBS-like device — •Gil Zimmermann[1,2], Marius Leyendecker[1,2], René Sondenheimer[1,2], and Fabian Steinlechner[1,2] — [1]Friedrich Schiller University, Jena, Germany — [2]Fraunhofer IOF, Jena, Germany

Non-Gaussian quantum states play an important role in quantum information, quantum computing and quantum sensing. There are many different protocols to generate different non-Gaussian states. One system, which is a generalisation of many of these protocols, is based on a so-called Gaussian boson sampling (GBS) type device. The advantage of this is that different non-Gaussian states can be produced with just one system. The GBS-like device consists of an N-mode linear interferometer that can implement any unitary transformation. N single mode Gaussian quantum states are injected into the interferometer and N-M modes are measured in the output with the aid of photon number resolving (PNR) detectors. A resulting quantum state is present in the remaining M output modes of the interferometer. By varying the propterties of the input states and the linear interferometer and considering different outcomes at the PNR detectors, optimisation algorithms can be designed regarding fidelity and generation probability. This allows us to find parameters for the best possible circuit that generates a specific M-mode non-Gaussian output state. In this work, a parameter study regarding the GBS-like device is carried out. For various single and multimode non-Gaussian states, we analyse the experimental feasibility under the presence of loss.

Q 35.7 Wed 16:15 HS 3118

Gaussian state generation with Gaussian-Boson-Sampling like setups — •Marius Leyendecker[1,2], Gil Zimmermann[1,2], René Sondenheimer[1,2], and Fabian Steinlechner[1,2] — [1]Friedrich Schiller University, Institute for Applied Physics, Abbe Center of Photonics, Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF , Jena, Germany

Non-Gaussian states have numerous applications in quantum computation, quantum metrology, and quantum communication. It has been shown that Gaussian Boson Sampling (GBS) devices in combination with detection post-selection can be used to generate many optical non-Gaussian states. This is implemented by interfering N input squeezed states on an N-mode linear interferometer. We study an optimization algorithm for an M-mode target state depending on the properties of the input states and the interferometer. These states are heralded by N-M photon-number resolving measurements on the other output states. As losses have a substantial influence on the fidelity of the produced output state, simple interferometer architectures comprising of only few optical elements, e.g. in a time-bin loop architecture with one loop, will be analyzed. While in [1] a variety of entangled Gaussian states have been demonstrated in a time-bin loop architecture and [2] explores the capability of the architecture for GKP states, we will explore the capabilities of the time-bin architecture for non-gaussian states with lower demands on experimental resources.

[1] Shuntaro Takeda et al. , DOI:10.1126/sciadv.aaw4530
[2] Takase, K., et al. DOI: 10.1038/s41534-023-00772-y

Q 36: Quantum Metrology and Interference

Time: Wednesday 14:30–16:30 Location: HS 3219

Q 36.1 Wed 14:30 HS 3219

Quantum parameter estimation with many-body fermionic systems and application to the quantum Hall effect — Olivier Giraud[1], Mark-Oliver Goerbig[2], and •Daniel Braun[3] — [1]Université Paris-Saclay, CNRS, LPTMS, 91405 Orsay, France — [2]Université Paris-Saclay, CNRS, Laboratoire de Physique des Solides, 91405 Orsay, France. — [3]Institut für theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany

Quantum metrology with electronic sensors requires the description of the system with a fermionic quantum field theory. To this end, we calculate the quantum Fisher information for a generic many-body fermionic system in a pure state depending on a parameter. The parameter can be imprinted in the basis states, the state coefficients, or in both. We apply our findings to the quantum Hall effect and evaluate the quantum Fisher information associated with the optimal measurement of the magnetic field for a system in the ground state. Remarkably, the occupation of electron states with high momentum enforced by the Pauli principle leads to a super-Heisenberg scaling of the sensitivity with a power law that depends on the geometry of the sensor.

Q 36.2 Wed 14:45 HS 3219

Entanglement-induced collective many-body interference — •Tommaso Faleo[1], Eric Brunner[2], Jonathan W. Webb[3], Alexander Pickston[3], Joseph Ho[3], Gregor Weihs[1], Andreas Buchleitner[2,4], Christoph Dittel[2,4,5], Gabriel Dufour[2], Alessandro Fedrizzi[3], and Robert Keil[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [3]Institute of Photonics and Quantum Sciences, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH14 4AS, UK — [4]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [5]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg, Germany

Entanglement and interference are hallmark effects of quantum physics, introducing particularly rich dynamics within systems of multiple (at least partially) indistinguishable particles.

By combining entanglement and many-body interference, we propose a novel quantum effect to realize genuine N-particle interference. We experimentally demonstrate this effect in a four-photon interferometer, where a highly visible interference pattern emerges upon the joint detection of all photons, while interference at lower-order particle correlators is strictly suppressed. The observed interference is a function of the four-particle collective phase, a genuine four-body property.

Q 36.3 Wed 15:00 HS 3219

All-optical Bose-Einstein condensate generation for micro-gravity operation — •Janina Hamann[1], Jan Simon Haase[1], Alexander Fieguth[2], Jens Kruse[2], Carsten Klempt[1,2], and the INTENTAS Team[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstraße 30b, 30167 Hannover

Atom interferometers are high-precision sensors for amongst others accelerations, rotations and magnetic fields. Space-borne atom interferometers promise a wide range of applications from geodesy to fundamental tests of physics. Their improved sensitivity due to prolonged interrogation times benefits from the macroscopic coherence length and slow expansion rates of Bose-Einstein condensates (BECs). A fundamental limit for the precision of AIs is the Standard Quantum Limit (SQL). The SQL can only be surpassed by using entangled ensembles of atoms in the interferometer. The INTENTAS project is designed as a source of entangled atoms that can be operated on a microgravity platform. To demonstrate sensitivity beyond the SQL rubidium atoms are cooled to a BEC, entangled with each other and detected with high precision. Evaporative cooling of the atoms is performed in a novel, robust crossed-beam optical dipole trap for all-optical BEC generation. In this talk the status of the project will be presented which includes characterization of the atom source on ground and first efforts towards the initial flight.

Q 36.4 Wed 15:15 HS 3219

Optimal Ramsey interferometry with echo protocols based on one-axis twisting — •Maja Scharnagl[1], Timm Kielinski[2], and Klemens Hammerer[2] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany — [2]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany

We study a variational class of generalized Ramsey protocols that include two one-axis twisting (OAT) operations, one performed before the phase imprint and the other after. In this framework, we optimize the axes of the signal imprint, the OAT interactions, and the direction of the final projective measurement. We distinguish between protocols that exhibit symmetric or antisymmetric dependencies of the spin projection signal on the measured phase. Our results show that the quantum Fisher information, which sets the limits on the sensitivity achievable with a given uniaxially twisted input state, can be saturated within our class of variational protocols for almost all initial twisting strengths. By incorporating numerous protocols previously documented in the literature, our approach creates a unified framework for Ramsey echo protocols with OAT states and measurements.

Q 36.5 Wed 15:30 HS 3219

Exploring few-shot quantum metrology with photonic qubits

— •Lukas Rückle[1,2], Jakob Budde[1,2], and Stefanie Barz[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universitity of Stuttgart, 70569 Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Universitity of Stuttgart, 70569 Stuttgart, Germany

The use of quantum states for metrology tasks has been proven to surpass classical limits on the precision of estimating parameters. Recently, the framework of *probably approximate correct (PAC) metrology* has been introduced [1]. It not only enables the estimation of a parameter in an arbitrarily big parameter space without prior knowledge, but also gives bounds for few- and single-shot metrology settings. It thus bridges the rather theoretical case of performing infinitely many measurements and practical metrology tasks.

Here, we present experimental results in a photonic metrology setting. We show how to use different states and measurements and how for each case to optimize the prediction strategy of the parameter that shall be estimated. Our work shows how to implement the given new framework of PAC metrology and thus helps improving the precision of applications that only allow for a few measurements, e.g. when measuring fast varying systems.

[1] Meyer et. al, arXiv-preprint, arXiv:2307.06370 (2023)

Q 36.6 Wed 15:45 HS 3219

Microcombs for Digital Holography — •Stephan Amann[1], Edoardo Vicentini[2], Bingxin Xu[1], Yang He[3], Theodor W. Hänsch[1], Qiang Lin[3], Kerry Vahala[4], and Nathalie Picqué[1,5] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]CIC nanoGUNE BRTA, Donostia-San Sebastian, Spain — [3]Department of Electrical and Computer Engineering, University of Rochester, Rochester, New York, USA — [4]T.J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, California, USA — [5]Max-Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany

Digital holography is a versatile lensless three-dimensional imaging technique that allows access to the amplitude and phase information of microscopic samples with interferometric precision. We report on microcombs, broad optical spectra consisting of phase-coherent narrow lines which are generated in a high-Q optical microresonator, as novel sources for digital holography. We generate a microcomb of 100 GHz line spacing in a lithium niobate microresonator by pulsed-pumping, which facilitates the reliable control of the line spacing. The combined information of all lines allows to increase the unambiguous axial range of the object reconstruction from less than a micrometer to 1.5 millimeter. Due to their broad spectral bandwidth and large line spacing on the order of hundreds of GHz, microcombs enable the precise imaging of millimeter-sized objects at fast measurement times. Envisioned applications range from nanometer-precision surface profilometry to hyperspectral microparticle analysis.

Q 36.7 Wed 16:00 HS 3219

Reducing Schmidt mode cross-overlap inside SU(1,1) interferometers — •Dennis Scharwald and Polina Sharapova — Department of Physics, Paderborn University, Warburger Straße 100, D-33098 Paderborn, Germany

One of the central challenges in quantum metrology is improving the quality of interferometers, for example measured by their phase sensitivity. Classical interferometers operating with coherent light are bound in their sensitivity by the shot noise limit (SNL), while nonlinear SU(1,1) interferometers may surpass it and reach the Heisenberg scaling. [1]

In our recent work [2], we use the numerical approach of integro-differential equations for the description of the parametric down-conversion (PDC) process to show that using an appropriately shaped mirror makes it possible to easily surpass the SNL in an SU(1,1) interferometer ("compensated" setup). In this work, we aim to extend the discussion presented therein by analyzing the overlap of the Schmidt modes and show how cross-coupling between modes of the two PDC sections is eliminated in the compensated setup. As a consequence, this leads to an improvement of the quality of the interferometer visible from the supersensitivity at high parametric gain.

[1] M. Manceau *et al.*, New J. Phys. **19**, 013014 (2017)
[2] D. Scharwald *et al.*, Phys. Rev. Res. **5**, 043158 (2023)

Q 36.8 Wed 16:15 HS 3219

Lateral shear interferometry for shape accuracy measurements of 3D-printed micro-optics — •Yanqiu Zhao[1,2], Leander Siegle[1,2], and Harald Giessen[1,2] — [1]4th Physics Institute, University of Stuttgart, Stuttgart, Germany — [2]Stuttgart Research Center of Photonic Engineering, Stuttgart, Germany

We compare several methods of lateral shear interferometry to assess the shape accuracy of 3D-printed micro-optics. Different aberrations are added deliberately to the lens design of the 3D-printed micro-optics and accuracy of the interferometric methods is evaluated. Accuracies up to lambda/100 can be reached for micro-optics with 140 micrometer diameter and around 570 micrometer focal lengths. Using gray scale lithography, 3D-printing aspherical singlets with RMS wavefront aberrations of only 0.01 lambda is realizable.

Q 37: Poster III

Time: Wednesday 17:00–19:00 Location: Tent B

Q 37.1 Wed 17:00 Tent B

A cryo-compatible, high-finesse all-fibre microcavity for REI spectroscopy — •Nicholas Jobbitt[1,4], Jannis Hessenauer[1,4], Evgenij Vasilenko[2,4], Vishnu Unni C.[1,4], Barbora Brachnakova[3,4], Senthil Kuppusamy[2,3,4], Mario Ruben[2,3,4], and David Hunger[2,3,4] — [1]Physikalisches Institut — [2]Institut für Quanten Materialien und Technologien — [3]Institute of Nanotechnology — [4]Karlsruher Institut für Technologie, Karlsruhe, Germany

Quantum technologies promise to enhance our current classical computing and communication infrastructure. Rare-earth ion (REI) based solid-state systems are ideal for this purpose due to the exceptional optical (4 ms) and spin (6 h) coherence times of their 4f $\rightarrow$ 4f transitions. However, key obstacles encountered while developing an efficient light-matter interface for quantum technologies using REI based solid-state systems are their long optical lifetimes ($T_{1,opt}$ $\sim$ms) and low branching ratios (<1%). Both these obstacles can be remedied by the integration of such systems into Fabry-Pérot microcavities. Here we present the development and testing of a cryo-compatible, high-finesse all-fibre microcavity designed for the purpose of REI spectroscopy. The cavity is largely monolithic in design with a single controllable degree of freedom, which reduces the mechanical noise present in the system (rms = 430 fm at cryogenic temperatures) and therefore allows us to maximise the Purcell-factor. Additionally, high quality (rms $\sim$1 nm) Eu^{3+} based crystalline organic molecules have been grown onto fibre-end facets, suitable for integration into the cavity.

Q 37.2 Wed 17:00 Tent B

Spatial Confinement of Atomic Excitation by Composite Pulses in Pr:YSO — •Niels Joseph[1], Markus Stabel[1], Nikolay Vitanov[2], and Thomas Halfmann[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Germany — [2]Department of Physics, St. Kliment Ohridski University of Sofia, Bulgaria

We experimentally demonstrate spatial confinement of atomic excitation by narrowband composite pulse sequences in Pr:YSO. In particular, we implement a variety of previously proposed sequences and compare their performance. We achieve population transfer that is spatially confined to an area significantly smaller than the diameter of the driving Gaussian-shaped laser pulses. Our experimental data agree well with a numerical simulation and confirm that the confinement improves with the number of pulses in the sequence. However, we find that inhomogeneous broadening in Pr:YSO reduces the performance, i.e., leading to the formation of additional rings around the localized centre. A theoretical treatment, confirmed by experiments, shows that the perturbing effect can be reduced by carefully choosing experimental parameters. Our experiments prove that narrowband composite pulses are a versatile tool to localize atomic excitation, potentially also below the diffraction limit. This could also be of relevance to quantum computation, as further generalized composite sequences enable arbitrary quantum gate operations in precisely confined spatial regions.

Q 37.3 Wed 17:00 Tent B

Getting topological invariants from snapshots: a protocol for defining and calculating topological invariants of systems with discrete parameter space — •Youjiang Xu and Walter Hofstetter — Goethe-Universität, Institut für Theoretische Physik, Frankfurt am Main, Germany

Topological invariants, including the Chern numbers, can topologically classify parameterized Hamiltonians. We find that topological invariants can be properly defined and calculated even if the parameter space is discrete, which is done by geodesic interpolation in the classifying space. We specifically present the interpolation protocol for the Chern numbers, which can be directly generalized to other topological invariants. The protocol generates a highly efficient algorithm for numerical calculation of the second and higher Chern numbers, by which arbitrary precision can be achieved given the values of the parameterized Hamiltonians on a coarse grid with a fixed resolution in the parameter space. Our findings also open up opportunities to study topology in finite-size systems where the parameter space can be naturally discrete.

Q 37.4 Wed 17:00 Tent B

Dissipative stabilization of molecular rotational states against blackbody radiation and spontaneous decay — •Brandon Furey, Mariano Monsalve, Zhenlin Wu, Stefan Walser, Elyas Mattivi, Rene Nardi, and Philipp Schindler — Universität Innsbruck

Novel quantum information encoding schemes are possible in the rotational degrees of freedom in molecules which are not available in atoms.[1] However, these codes are vulnerable to rotational transitions induced by the environment; namely, blackbody radiation and spontaneous decays. Encoding in a single rotational manifold may enable protection against such decoherence.[2] Theoretically, we are developing a dissipative quantum error correction (QEC) scheme which can be continuously applied to stabilize a rotational superposition.

Experimentally, we aim to demonstrate state preparation, coherent control, and the creation of superpositions of rotational states in CaH^+ or $CaOH^+$ molecular ions using Raman setups with two CW laser beams and another with an optical frequency comb.[3] This could pave the way for exploring QEC codes based on trapped molecular ions.

[1] V. Albert, et al. Phys. Rev. X 10, 031050 (2020)
[2] S. Jain, et al. arXiv:2311.12324 [quant-ph] (2023)
[3] C. Chou, et al. Science 367, 1458 (2020)

Q 37.5 Wed 17:00 Tent B

A versatile algorithm for ion configuration determination in linear ion crystals consisting of mixed atomic and molecular ion species — •Stefan Walser, Brandon Furey, Zhenlin Wu, Rene Nardi, Mariano Isaza Monslave, Elyas Mattivi, and Philipp Schindler — Insitut für Experimentalphysik, Universität Innsbruck

Trapped atomic ions enabled a variety of developments in quantum information and computation in the last two decades. Recently efforts have been made to extend this well studied platform to molecular ions. The latter's additional degrees of freedom might provide a more resource efficient toolkit for quantum computational processes. Therefore, atomic logic ions are co-trapped with molecular ions for sympathetic cooling, state preparation, and readout. Often molecular ions cannot be observed directly but their presence is indicated by vacancies in trapped ion chains. Thus, new methods to rapidly and precisely identify and locate molecular ions are required. We present a featureful algorithm based on a custom peak finder and template fitting which processes image data of the ion crystal. It reliably counts bright logic and dark molecular ions and measures the ion configuration in real time on ms timescales. This provides a versatile basis for automated in-time decision making in various novel experiments.

Q 37.6 Wed 17:00 Tent B

Non-Markovianity of the nonlinear Caldeira-Leggett model — •Moritz F. Richter and Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Germany

Employing the simulation method of the hierarchical equations of motion (HEOM), we investigate the nonlinear Caldeira-Legget model, a paradigmatic microscopic system-reservoir model used in open system theory. In particular, we study the impact of a nonlinear coupling of the open system to the reservoir modes on the size of memory effects quantified by the trace distance based measure for non-Markovianity [1]. We also discuss the role of instabilities of the HEOM method and how these influence the numerical determination of the non-Markovianity measure.

[1] Breuer H-P, Laine E-M, Piilo J and Vacchini B; 2016 "Colloquium: non-Markovian dynamics in open quantum systems"; Rev. Mod. Phys. 88 021002

Q 37.7 Wed 17:00 Tent B

Characterization of squeezing sources using Hong-Ou-Mandel interference measurements — •Florian Lütkewitte, Kai Hong Luo, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

Gaussian boson sampling (GBS) is a promising platform for demonstrating photonic quantum advantage and noisy intermediate-scale quantum computing. The performance of such systems depends on the ability to produce high-quality single-mode squeezed states. One can produce such states by interfering the two modes of a decorrelated, indistinguishable two-mode squeezed state generated in potassium titanyl phosphate waveguides on a balanced beam splitter. However, one needs to confirm that the generated states reach the qualities required for these highly demanding applications. In this work, we investigate the possibilities and limitations of using Hong-Ou-Mandel interference as a characterization method for these squeezed light sources.

Q 37.8 Wed 17:00 Tent B

Energy level renormalization in strongly coupled open quantum systems — •Alessandra Colla, Florian Hasse, Frederike Doerr, Ulrich Warring, Tobias Schaetz, and Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

When a quantum system interacts strongly with a general environment, the interaction energy they share can be of the same magnitude as the expectation value of the bare system Hamiltonian, and can no longer be neglected. Is it then justified to still consider the bare system Hamiltonian as the operator determining the energy levels of the system? If we observe the system while it is coupled to the environment, would we witness signatures of the interaction energy in the system? If so, how? We show that in the case of a simple Jaynes-Cummings model, the energy levels of the two-level system undergo a renormalization due to the strong interaction with the mode, in accordance with our recent proposal for a theory of open system quantum thermodynamics [1]. This energy level shift, which is in general time-dependent, is determined by the coupling strength and by the initial state of the mode (typically its associated temperature). Furthermore, it is experimentally accessible in suitable platforms, and leads to the well known Lamb-shift for zero mode temperature and in the limit of large detuning.

[1] A. Colla and H.-P. Breuer, Phys. Rev. A 105, 052216 (2022).

Q 37.9 Wed 17:00 Tent B

Speeding up Quantum Annealing with coupling to meter — •Mykolas Sveistrys[1], Giovanna Morigi[2], and Christiane P. Koch[1] — [1]Fachbereich Physik and Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Quantum annealing is a quantum computing paradigm with great promise, but also many doubts whether it can produce speedups over classical calculations. To speed up quantum annealing calculations, we introduce a (potentially) dissipative protocol that involves a meter qubit coupled to the qubit array (the system) encoding the annealing problem. The coupling is designed to commute with the system Hamiltonian at all times. Depending on the state of the meter qubit, two mechanisms emerge that result in enhanced adiabaticity and, therefore, a faster time-to-solution: dephasing of the system in its instantaneous eigenbasis, and an effective rescaling of the system's energy levels. We first analyse analytically the conditions where each mechanism dominates, finding that under some circumstances, one should optimize for maximal energy rescaling at the cost of zero dephasing. We then numerically demonstrate the speedup such a protocol yields. We show a 3.6x speedup in time-to-solution on a small-scale instance of the Minimum Weighted Vertex Cover Problem, and a 28% speedup in time-to-solution, seemingly without any dependence on problem size, on a larger benchmark of random Ising models.

Q 37.10 Wed 17:00 Tent B

Quantum Feedback Control for Quantum Error Correction on Superconducting Qubits — •Anton Halaski and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

Continuous quantum error correction (QEC) is required in many situations in which the limit of a strong projective measurement cannot be applied. Recently, Atalaya et al. [*Phys. Rev. A* **103**, 042406 (2021)] proposed a continuous QEC scheme for quantum information applications which involve continuously varying Hamiltonians. This scheme relies on a sufficiently strong and continuous two-qubit parity measurement to extract the error syndromes. To implement such a measurement is particularly challenging, since one has to perform a fast, nonlocal measurement while at the same time not introducing any errors to the information encoded in the qubits. We investigate to what extent this task can be accomplished using current circuit QED architecture. Recent proposals for continuous parity measurements in this field rely on the so-called dispersive regime in which the transmons are far detuned from a resonator which acts as the meter for the parity measurement. As a result, transmons and resonator are only weakly coupled and the measurement is slow. We explore how one can achieve speedups by going to the quasi-dispersive regime. Measurements based on the quasi-dispersive regime could then be utilized to enhance the resilience of Atalaya et al.'s and future QEC protocols.

Q 37.11 Wed 17:00 Tent B

Dilute measurement-induced cooling into many-body ground states — •Josias Langbehn[1], Kyrylo Snizhko[2], Igor Gornyi[3], Giovanna Morigi[4], Yuval Gefen[5], and Christiane Koch[1] — [1]Freie Universität Berlin, Berlin, Germany — [2]Université Grenoble Alpes, Grenoble, France — [3]Karlsruhe Institute of Technology, Karlsruhe, Germany — [4]Saarland University, Saarbrücken, Germany — [5]Weizmann Institute of Science, Rehovot, Israel

Cooling a quantum system to its ground state is important for the characterization of non-trivial interacting systems, and in the context of a variety of quantum information platforms. In principle, this can be achieved by employing measurement-based passive steering protocols, where the steering steps are predetermined and are not based on measurement readouts. However, measurements, i.e., coupling the system to auxiliary quantum degrees of freedom, is rather costly, and protocols in which the number of measurements scales with system size will have limited practical applicability. Here, we identify conditions under which measurement-based cooling protocols can be taken to the dilute limit. For two examples of frustration-free one-dimensional spin chains, we show that steering on a single link is sufficient to cool these systems into their unique ground states. We corroborate our analytical arguments with finite-size numerical simulations and discuss further applications.

Q 37.12 Wed 17:00 Tent B

Suppression of Servo-Phase Noise for High-Fidelity Rydberg Excitations — Philipp Herbig[1], Ben Michaelis[1], Nejira Pintul[1], Tobias Petersen[1], Jonas Rauchfuss[1], Oscar Murzewitz[1], Clara Schellong[1], Jan Deppe[1], Till Schacht[1], Alexander Ilin[1], •Koen Sponselee[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center for Optical Quantum Technologies, Hamburg, Germany — [2]Institute for Quantum Physics, Hamburg, Germany

Neutral-atom quantum computers require highly-stable lasers for resonant excitation, which is usually achieved with a Pound-Drever-Hall (PDH) locking scheme. However, this feedback scheme creates servo bumps, which can severely limit excitation fidelities if the servo bandwidth frequency is similar to the Rabi frequency. A feed-forward scheme by Li et al. [1] supresses these servo bumps, and is here implemented in our Ytterbium quantum-computing experiment.

We are setting up our experiment to trap neutral 171-Ytterbium atoms in optical tweezers, providing several options for qubits. A 301.5 nm laser can then be used to excite $^3\mathrm{P}_0$ state atoms to an ($n > 50$) $^3\mathrm{S}_1$ Rydberg state, entangling two neighbouring qubits with expected Rabi frequencies on the order of MHz. The fundamental of this laser is first stabilised to a cavity with a PDH lock. The servo bumps, about 500 kHz away from the carrier, are supressed by more than 20 dB using this scheme [1]. Simulations indicate that this method leads to significantly better excitation fidelities.

[1] Li et al., PRA 18, 064005 (2022)

Q 37.13 Wed 17:00 Tent B

Analysis of motional heating during ion-transport through RF junctions in a surface-electrode Paul trap — •Phil Nuschke[1], Florian Ungerechts[1], Rodrigo Munoz[1], Janina Bätge[1], Axel Hoffmann[1,2], Teresa Meiners[1], Brigitte Kaune[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Ger- many — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Ion transport through RF junctions is essential for the scaling of trapped-ion quantum processors in the QCCD architecture. It is crucial to minimise the heating rates during ion transport through an RF junction to avoid excessive overhead in sympathetic re-cooling. This becomes increasingly important the greater the number of qubits, since transport times become a limiting factor. The interplay of transport speed and heating is complex and comprises effects from anomalous heating, pseudopotential gradient heating, non-adabaticities imperfect transport waveform realizations. Here we discuss estimates of pseudopotential gradient heating vs. anomalous heating as a function of transport speed.

Q 37.14 Wed 17:00 Tent B

Fault-Tolerant One-Bit Addition with the Smallest Interesting Colour Code — •Yang Wang[1], Selwyn Simsek[2], and Ben Criger[2] — [1]3. Physikalisches Institut, ZAQuant, University of Stuttgart, Allmandring 13, 70569 Stuttgart, Germany — [2]Quantinuum, Terrington House, 13-15 Hills Road, Cambridge, CB2 1NL, UK

Fault-tolerant operations based on stabilizer codes are the state of the art in suppressing error rates in quantum computations. Most such codes do not permit a straightforward implementation of non-Clifford logical operations, which are necessary to define a universal gate set. As a result, implementations of these operations must either use error-correcting codes with more complicated error correction procedures or gate teleportation and magic states, which are prepared at the logical level, increasing overhead to a degree that precludes near-term implementation. In this work, we implement a small quantum algorithm, one-qubit addition, fault-tolerantly on the Quantinuum H1-1 quantum computer, using the 8-qubit error detection code. By removing unnecessary error-correction circuits and using low-overhead techniques for fault-tolerant preparation and measurement, we reduce the number of error-prone two-qubit gates and measurements to 36. We observe arithmetic errors with a rate of ˜ 0.11% for the fault-tolerant circuit and ˜ 0.95% for the unencoded circuit.

Q 37.15 Wed 17:00 Tent B

Microwave near-field and stimulated-Raman quantum control of $^9\mathrm{Be}^+$ ions in a cryogenic surface-electrode trap — •Emma Vandrey[1], Sebastian Halama[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38166 Braunschweig, Germany

Trapped-ion qubits are a promising hardware platform for quantum computing and quantum simulation. In our group, we employ surface-electrode Paul traps to confine $^9\mathrm{Be}^+$ ions and encode the qubits in two hyperfine levels of these ions. For motional ground-state cooling and quantum logic gates, the ability to drive sideband and carrier transitions with frequencies in the microwave regime is required. Integrating microwave conductors into the surface-electrode trap allows the ion's internal and motional states to be controlled using oscillating magnetic fields and an oscillating magnetic gradient.

Alternatively, we can apply stimulated-Raman laser pulses to drive transitions at microwave frequencies. The laser light for this setup is generated via sum-frequency generation and subsequent second harmonic generation. Variable frequency control is implemented using a double-pass acousto-optic modulator setup with a geometry that is inherently stable with respect to thermal effects.

Both of these approaches were implemented in the context of a cryogenic ion trap apparatus. We will report on the status of the project and on a new generation of segmented multi-ion trap chips to be implemented in this environment.

Q 37.16 Wed 17:00 Tent B

Automated modular design of surface electrode Paul traps for quantum computing — •Brigitte Kaune[1], Janina Bätge[1], Axel Hoffmann[1,2], Rodrigo Munoz[1], Florian Ungerechts[1], Teresa Meiners[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1,

30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Surface electrode Paul traps with integrated microwave conductors for near-field quantum control are one of the most promising approaches for scalable quantum processors. In the trap design process, numerical simulations using e.g. FEM solvers are crucial. Building the system can be time consuming and slows down the design process. We present progress on a modular trap zone component library for rapid design of multilayer surface electrode Paul traps with integrated microwave conductors. The library is currently being written for automated building with a commercial high-frequency system simulation design software, allowing further pre-definition of excitations and analysis setups to speed up the design process as efficiently as possible.

Q 37.17 Wed 17:00 Tent B

Realization of elementary operations for continuous-variable quantum computers — •Freyja Ullinger, Rudi Pietsch, Alexander Sauer, and Matthias Zimmermann — German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

Continuous-variable quantum computers encode information and perform calculations based on continuous degrees of freedoms, such as e.g. position or momentum. In this case, the elementary logical gates are characterized by continuous transformations such as displacement, rotation and shearing[1,2]. However, the implementation of these gates is limited to the experimentally available operations to manipulate continuous quantum states. Therefore, it is necessary to develop schemes that are applicable in a variety of physical systems.

In this poster, we present a representation-free theory to realize the displacement, rotation and shearing operator for particles with non-vanishing mass. Our method is solely based on the application of linear and quadratic potentials that either act instantaneously or for a finite period of time, which makes our approach versatile for various continuous quantum systems.

[1] S. L. Braunstein and A. K. Pati, *Quantum Information with Continuous Variables* (Kluwer Academic Publishers, Dordrecht, The Netherlands, 2003).

[2] S. L. Braunstein and P. van Loock, Rev. Mod. Phys. **77**, 513 (2005).

Q 37.18 Wed 17:00 Tent B

QuMIC - Towards a scalable ion trap with integrated high-frequency control — •Marco Bonkowski[1], Sebastian Halama[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Surface-electrode ion traps are a promising candidate for a scalable quantum computer [1]. A major challenge in this approach to quantum computing is the integration of qubit control into the device. With the microwave near-field approach [2], qubit control realized by microwave conductors that are integrated into the ion trap naturally scale with the trap itself. However, the microwave signal generation currently takes place outside of the vacuum chamber in which the ion trap is located. The QuMIC project researches and develops novel highly integrated BiCMOS chips at high frequencies and their hybrid integration with quantum electronics like ion traps. This approach enables the scalability of a quantum computer to a large number of qubits and a drastic reduction in the number of required high-frequency lines, which also benefits the cooling capabilities of the cryostat used to cool down the ion trap to around 4K. We describe the setup of a cryogenic ion trap apparatus with the associated laser systems for beryllium. The apparatus will be used as a testing stand for rapid trap testing, such as the ion traps with integrated microwave sources developed for QuMIC. We will report on the current status of the project.

[1] Chiaverini et al., Quantum Inf Comput 5, 419-439 (2005)

[2] Ospelkaus et al., Phys. Rev. Lett. 101, 090502 (2008)

Q 37.19 Wed 17:00 Tent B

RF junctions for register-based trapped-ion quantum processors — •Florian Ungerechts[1], Rodrigo Munoz[1], Janina Bätge[1], Axel Hoffmann[1,2], Teresa Meiners[1], Brigitte Kaune[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

RF junctions are crucial for scaling trapped-ion quantum processors connecting the specialized zones in the QCCD architecture. We discuss the design and optimization techniques of such an RF junction for a surface-electrode trap, focusing on the implications for through-junction ion transport. We present an optimized RF X-junction feasible for the transport of single $^9Be^+$ ions and multilayer microfabrication.

Q 37.20 Wed 17:00 Tent B

Multiplexing of the transport through an X-junction ion trap — •Janina Bätge[1], Rodrigo Munoz[1], Florian Ungerechts[1], Axel Hoffmann[1,2], Teresa Meiners[1], Brigitte Kaune[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

One of the current problems in scaling up ion trap quantum processors is the large number of control signals. Therefore, concepts to reduce the amount of required signals are needed. We present a concept for multiplexing the control signals for a surface electrode ion trap with an X-junction. One of the key issues is the estimation of the minimum number and the appropriate combination of signals needed for through-junction transport.

Q 37.21 Wed 17:00 Tent B

Optical integration with femto-second laser written waveguides — •Marco Schmauser[1], Philipp Schindler[1], Thomas Monz[1], Marco Valentini[1], Jakob Wahl[1,2], Alexander Zesar[2,3], Klemens Schueppert[2], Bernhard Lamprecht[4], Philipp Hurdax[4], Clemens Rössler[2], and Rainer Blatt[1,5] — [1]Universität Innsbruck, Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Universität Graz, Graz, Austria — [4]Joanneum Research, Weiz, Austria — [5]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Austria

Current ion trap quantum computing systems usually make use of free-space optics to deliver the light to the ions. This practice makes the setups susceptible to drifts and vibrations and limits the number of ions which can be manipulated. For a scalable system it is thus necessary to increasingly integrate optical elements from external components directly into the ion trap.

We use femto-second laser pulses to write single-mode and polarization-maintaining waveguides directly into borofloat glass. Unlike other materials used in CMOS technology, borofloat glass is transparent for ultraviolet light required for the manipulation of 40Ca+ ions. Henceforth, a microstructured surface trap was realized featuring two of these waveguides, one for 397nm light and one for 729nm light. In parallel, we build up an integrated cryogenic quantum computing system to enable fast trap testing and to investigate the quality of the light delivery to the ions.

Q 37.22 Wed 17:00 Tent B

Building a tweezer array with programmable connectivity — •Johannes Schabbauer, Stephan Roschinski, Marvin Holten, and Julian Léonard — TU Wien, Atominstitut, Vienna Center for Quantum Science and Technology (VCQ), Austria

Creating multi-particle entangled states deterministically is one of the big challenges for quantum information processing. While this was achieved locally in several systems, for instance with arrays of optical tweezers using Rydberg interactions between atoms, we present a novel platform to engineer non-local interactions between single atoms in optical tweezers by strong coupling to an optical cavity. In our experiment we use a fiber cavity, which enables good optical access for placing high resolution microscopes above and below the cavity. These microscopes are used for creating the tweezer array, single-site resolved imaging, and addressing single atoms in the optical tweezers. Our experiment enables us to study multi-particle entangled states and many-body systems with programmable interactions. The dispersive shift of the cavity resonance can be used to perform non-destructive measurements and to implement protocols for dissipative state preparation.

Q 37.23 Wed 17:00 Tent B

Coherent control of strontium atoms trapped in an optical lattice and applications for quantum simulations — •Jan Geiger[1,2], Valentin Klüsener[1,2], Sebastian Pucher[1,2], Felix Spriestersbach[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Neutral atoms trapped in optical lattices allow for precise measurements, quantum simulation, and quantum computation. Here, we demonstrate the essential building blocks for a quantum simulator: state-dependent trapping, large, homogeneous optical lattices, single-atom resolved fluorescence imaging, and high-resolution optical spectroscopy. We present the first coherent excitation of the ultranarrow $^1S_0$-$^3P_2$ magnetic quadrupole transition in ^{88}Sr. Building on this work, we demonstrate high-fidelity Rabi oscillations between the $^3P_0$ and $^3P_2$ state. The developed spectroscopy methods enable us to perform quantum simulations on strongly coupled light-matter interfaces.

Q 37.24 Wed 17:00 Tent B

Quantum speed limit dependence on the number of controls in a qubit array — •David Pohl, Fernando Gago-Encinas, Matthias Krauss, and Christiane P. Koch — Arnimallee 14, 14195 Berlin

Universal quantum computing requires operator controllability of the qubit array. This is typically realized via qubit-qubit couplings and local external controls on every qubit which becomes challenging when scaling to large numbers of qubits. We have shown recently that the number of external controls can be reduced to the extreme limit of a single control. However, this comes at the expense of longer gate durations. Here, we investigate the gate duration depending on the number of local controls. In particular, we show that reducing controls increases the quantum speed limit (the shortest time to generate a quantum gate). We determine this limit for a universal set of gates for different 3-qubit systems using quantum optimal control.

Q 37.25 Wed 17:00 Tent B

Realising fast readout for Rydberg arrays — •Balázs Dura-Kovács[1,2], Mehmet Öncü[1,2], Jacopo De Santis[1,2], Sebastian Ruffert[1,2], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany

Ordered arrays of neutral atoms provide an appealing platform for quantum simulation and quantum computation. Laser-cooled atomic gases allow for simulating quantum many-body systems with unprecedented control over microscopic degrees of freedom. The recent progress on tweezer-based atom arrays and quantum gas microscopes has enabled microscopic detection and manipulation of such systems down to the level of single atoms. Here, we present our progress on an experimental platform aimed at achieving cavity-assisted, non-destructive, local readout of atoms in a tweezer array. Long-range and tunable interactions between highly-excited Rydberg states make the platform suited to simulate spin models and – together with the fast cavity-based readout – form the architectural basis for the realisation of a scalable quantum computing platform.

Q 37.26 Wed 17:00 Tent B

Optical tweezers for trapped ion quantum simulation — •Rima X. Schüssler, Matteo Mazzanti, Clara Robalo Pereira, Nella Diepeveen, Louis Gallagher, Zeger Ackerman, Arghavan Safavi-Naini, and Rene Gerritsma — University of Amsterdam, Amsterdam, The Netherlands

Trapped ion crystals offer an advanced platform for quantum computation and simulation. However, limited control over the interactions between the ions constrains the range of accessible Hamiltonians.

In our experiment, we plan to combine trapped ions with microtraps in the form of optical tweezers. These additional potentials will allow us to manipulate the phonon mode spectrum and thereby control the spin-spin interactions of the ions in a Paul trap. We will use a high power 1030nm laser far detuned from any transition in Yb^+. The tweezers will be produced by a spatial light modulator and focused on the ions to a waist of a few μm with a high NA objective. With the right tweezer pattern [1], we can then use the system to study various Hamiltonians of interest, for example, Hamiltonians on a kagome lattice in 2D ion crystals.

[1] J.D. Espinoza, M. Mazzanti, K. Fouka, R.X. Schüssler, Z. Wu, P.Corboz Phys. Rev. A 104, 013302 (2021).

Q 37.27 Wed 17:00 Tent B

Progress towards a fault tolerant microwave-driven two qubit quantum processor — •Hardik Mendpara[1,2], Nicolas Pulido-Mateo[1,2], Markus Duwe[1,2], Alexander Onkes[1,2], Ludwig Krinner[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover — [2]Physikalisch-Technische Bundesanstalt, Braunschweig

A universal quantum gate set can be realized by the combination of single-qubit gates and one entangling operation. Here, we realize such a universal gate-set using the microwave near-field approach [1]. We trap $^9Be^+$ ions in a surface electrode trap and perform the quantum logic operations with embedded electrodes. The individual qubits are addressed by micromotion sidebands [2] and the entangling gate is performed via a Mølmer-Sørensen type interaction. We approach an infidelity of 10^{-3} with entangling gates using partial state tomography and in a computational context we extract a composite process infidelity of $3.4(4) \times 10^{-2}$ using the cycle benchmarking protocol [4]. We report on recent progress on improving the gate fidelities and characterizing the quantum process errors.

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

Q 37.28 Wed 17:00 Tent B

Employing continuous quantum systems to solve optimization problems — •Alexander Sauer, Sebastian Luhn, and Jannes Weghake — DLR e.V., Institut für Quantentechnologien, Ulm

At land, sea and in the air mobility and traffic management offer a vast amount of problems with a large potential of optimization with quantum computers, e.g. service scheduling, route planning, or path optimization. Many of these problems can be described at a fundamental level by the traveling salesman problem (TSP), in which the shortest route while visiting each point exactly once is to be found [1]. The TSP has already received a lot of attention in the quantum computing community, for example, implementations for adiabatic quantum annealers exist and have been tested [2,3]. We investigate the TSP with a focus on going beyond qubits by employing continuous quantum systems. Using bosonic Qiskit we simulate potential algorithms for solving the TSP and compare their performance.

[1] Flood, M. M., The traveling-salesman problem. Operations research, 4(1), 61-75, (1956).

[2] Martoňák, Roman, Giuseppe E. Santoro, and Erio Tosatti., Quantum annealing of the traveling-salesman problem. Physical Review E 70.5: 057701, (2004).

[3] Jain, S., Solving the traveling salesman problem on the d-wave quantum computer. Frontiers in Physics, 646, (2021).

Q 37.29 Wed 17:00 Tent B

Extreme power spectre effects with special pulse shapes: Power narrowing and power broadening — •Ivo Mihov — Department of Physics, St Kliment Ohridski University of Sofia, 5 James Bourchier blvd, 1164 Sofia, Bulgaria

The effects of the excitation pulse shape on the transition line of the qubit are detrimental. Some pulse shapes are known to exhibit power broadening (the Rabi model). Others do not depend on the Rabi frequency whatsoever (the Rosen-Zener model). We have even shown that a family of pulse shapes reverse the power broadening effect and exhibits power narrowing instead. They have been theoretically and experimentally demonstrated using IBM Quantum hardware.

In this work we focus on pulse shapes that produce a case of extreme power broadening patterns. They are usually made of a convex shape that starts and ends with a sharp discontinuity, similar to the rectangular pulse shape. The two pulse shapes that were used throughout the experiment were of the form $\Omega_1(t) = \Omega_0 t^{2N}$, where N is a non-negative integer, and $\Omega_2(t) = \Omega_0(1 + \beta t^2)$, where β can be any real number (may also be negative). We have experimentally shown an increase in the 9pi excitation maximum of our custom pulse by a factor of approximately 5 over the one with the simple rectangular pulse using IBM Quantum system ibmq_manila.

Q 37.30 Wed 17:00 Tent B

Entanglement generation in photonic two photon quantum walks — •Federico Pegoraro, Philip Held, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS) Warburger Str. 100, 33098, Paderborn, Germany

Entanglement constitutes a fundamental property for the development of quantum algorithms and protocols capable of outperforming their classical counterparts in terms of speed and resource efficiency. In order to be able to exploit the advantages offered by entanglement one must be capable of producing such a resource. For this reason we study how to generate entanglement in a photonic setting using a well known quantum process: the multi-walker quantum walk (QW). In this process a number of quantum objects, the "walkers", evolve in a position space according to the update of an internal degree of freedom called coin. We use a photon pair produced via type-II spontaneous parametric down-conversion as walkers: their coins are encoded into the respective polarization states, while for the position space we employ a time-multiplexing loop where a given arrival time corresponds to a certain output position. The two photons are launched in the QW and propagate in the setup for a certain amount of roundtrips after which they are released and detected. By performing joint polarization-tomography on the walkers at the output of the QW, we can evaluate the dynamics of entanglement creation and distribution in the QW.

Q 37.31 Wed 17:00 Tent B

Development of time-multiplexed fiber-based quantum walks — •Moritz Borchardt, Federico Pegoraro, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

The random walk stands as a powerful tool within the realm of computer science. Its quantum mechanical counterpart, referred to as the quantum walk, opens up avenues for developing even more efficient algorithms tailored to address both current and future (quantum) computing challenges. Among various possibilities, photonic based implementations have proven to be advantageous in terms of resources needed to realize the quantum walk evolution. Due to complex alignment procedures and large system size, opting for partial integration seems to be a reasonable approach in terms of scaling. Additionally, recent results highlight that achieving the necessary modulation speed, crucial for effective quantum computing, is only feasible through the use of integrated modulators. In fact, integrated thin-film lithium niobate modulators have shown bandwidths in excess of 100 GHz. Here we take a step in this direction and present an implementation of an integrated time-multiplexed quantum walk that relies only on fiber loops and directional couplers. We experimentally demonstrate the quantum walk dynamics, and we investigate effects of unbalanced losses in the setup with an outlook on dynamic implementations requiring fiber based active components that would have an impact on the system efficiency.

Q 37.32 Wed 17:00 Tent B

Quantum Information Processing with trapped-ion based Qudits — •Lukas Gerster[1], Peter Tirler[1], Manuel John[1], Lisa Parigger[1], Michael Meth[1], Claire Edmunds[1], Pavel Hrmo[1], Benjamin Wilhelm[1], Martin van Mourik[1], Rainer Blatt[1,2,3], Philipp Schindler[1], Thomas Monz[1,3], and Martin Ringbauer[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25/4, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, 6020 Innsbruck, Austria — [3]AQT, Technikerstraße 17, 6020 Innsbruck, Austria

Quantum Information Processing has been predominantly developed using qubits, two level quantum systems, as its fundamental building blocks. However many physical implementations of qubit-based quantum processors actually use multilevel systems, from which only two levels are selected for information encoding. By extending the encoding information in multi-level qudit basis states, one directly expands the Hilbert space available for computation, and promises more efficient compilation with respect to the number of required entangling gates. We experimentally demonstrate an implementation of a native two-qudit entangling gate up to dimension 5 in a trapped-ion system, and we present a new experimental apparatus dedicated for exploring higher dimensional qudit protocols and algorithms up to qudit dimension d=7.

Q 37.33 Wed 17:00 Tent B

Gerchberg-Saxton Algorithm for Optical Tweezer Arrays — •Jonas Rauchfuss[1], Nejira Pintul[1], Tobias Petersen[1], Oscar Murzewitz[1], Clara Schellong[1], Jan Deppe[1], Koen Sponselee[1], Alexander Ilin[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center of Optical Quantum Technologies University of Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg

Neutral atoms have shown to be a promising candidate for building large scale quantum computing devices, with fast high-fidelity single and two-qubit gates as well as flexible initialisation and readout. Recently, alkaline earth (-like) atoms such as ytterbium (Yb) and strontium (Sr) have shown to offer promising ways to overcome some of the main challenges on the road to large scale, fully programmable quantum computers with decent effective circuit depth. In this context, uniformly trapping atoms within optical tweezers is crucial for ensuring prolonged coherence times and mitigating qubit dephasing. This poster focuses on the implementation of two distinct variations of the Gerchberg-Saxton algoritm (GSA) utilized for generating and homogenising optical tweezer arrays using a spatial light modulator (SLM). Moreover, we implemented a camera feedback into our system to improve optimization and responsiveness. Our analysis compares the efficacy of these approaches in creating intermediate-scale, uniform optical tweezer arrays.

Q 37.34 Wed 17:00 Tent B

Gerchberg-Saxton Algorithm for Optical Tweezer Arrays — •Jonas Rauchfuss[1], Nejira Pintul[1], Tobias Petersen[1], Oscar Murzewitz[1], Clara Schellong[1], Jan Deppe[1], Koen Sponselee[1], Alexander Ilin[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center of Optical Quantum Technologies University of Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institute for Quantum Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg

Neutral atoms have shown to be a promising candidate for building large scale quantum computing devices, with fast, high-fidelity single and two-qubit gates as well as flexible initialisation and readout. Recently, alkaline earth (-like) atoms such as ytterbium (Yb) and strontium (Sr) have shown to offer promising ways to overcome some of the main challenges on the road to large scale, fully programmable quantum computers with decent effective circuit depth. In this context, uniform trapping of atoms within optical tweezers is crucial for ensuring prolonged coherence times and mitigating qubit dephasing. This poster focuses on the implementation of two distinct variations of the Gerchberg-Saxton algorithm (GSA) utilized for generating and homogenising optical tweezer arrays using a spatial light modulator (SLM). Moreover, we implemented a camera feedback into our system to improve optimization and responsiveness. Our analysis compares the efficacy of these approaches in creating intermediate-scale, uniform optical tweezer arrays.

Q 37.35 Wed 17:00 Tent B

Solving optimization problems with local light shift encoding on Rydberg quantum annealers — •Kapil Goswami[1], Rick Mukherjee[1], Herwig Ott[2], and Peter Schmelcher[1] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Department of Physics and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau,67663 Kaiserslautern, Germany

The current era of quantum computers is characterized by a limited number of qubits, high levels of noise, and imperfect quantum gates. Despite these limitations, neutral atom analog quantum computers offer opportunities for exploring the potential advantages. We provide an efficient framework to solve combinatorial optimization problems such as Maximum Cut (Max-Cut) and Maximum Independent Set (MIS) on a Rydberg quantum annealer. Our system employs locally controlled light shifts on individual qubits in a many-body Rydberg setup, mapping graph problems to the Ising spin model. Using optimal control methods, our numerical simulations implement the local-detuning protocol while globally driving the Rydberg annealer to the desired many-body ground state, which is the solution to the optimization problem. The solutions are obtained for prototype graphs with varying sizes at time scales well within the system lifetime and with approximation ratios close to one. A comparative analysis with classical simulated annealing is provided which highlights the advantages of our scheme in terms of system size, hardness of the graph, and the number of iterations required to converge to the solution.

Q 37.36 Wed 17:00 Tent B

Quantum gas microscopy of strongly correlated states of the Fermi-Hubbard model — •Johannes Obermeyer[1], Dominik Bourgund[1], Petar Bojovic[1], Si Wang[1], Titus Franz[1], Thomas Chalopin[1], Immanuel Bloch[1,2], and Timon Hilker[1] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Ludwig-Maximilians-Universität, München, Germany

The Fermi-Hubbard model describes phenomena in condensed matter physics including strange metals, the pseudogap or the formation of stripes. The model possibly even explains the fundamental mechanisms of high-Tc superconductivity. With our quantum gas microscope based on ultracold Li-6 atoms we are able to prepare states of the two-dimensional Fermi-Hubbard model and probe the system with single site spin and density resolution. We use an optical superlattice to engineer the Hamiltonian to a one, two or mixed dimensional system. On top of our optical lattice a potential landscape gets projected by a digital mirror device that facilitates the control of the hole doping in the Fermi-Hubbard system. We present our observations of holes moving in an antiferromagnetic background. These observations mark the onset of exploring antiferromagnetism and the highly anticipated pseudogap phase of the doped Fermi-Hubbard model. In future experiments, we want to explore more fundamental predictions of the Fermi-Hubbard model like Mott excitons and aim to decrease our system temperature exerting bilayer cooling. Additionally, the double well structure of the superlattice is expected to enable the realization of collisional two-qubit gates for digital quantum computing.

Q 37.37 Wed 17:00 Tent B

Quantum Computation with Neutral Alkaline-Earth-like Ytterbium Rydberg Atoms in Optical Tweezer Arrays — •Nejira Pintul[1,2], Tobias Petersen[1,2], Nicolas Heimann[1,2], Lukas Broers[1,2,3], Koen Sponselee[1,2], Alexander Ilin[1,2], Jonas Rauchfuss[1,2], Oscar Murzewitz[1,2], Clara Schellong[1,2], Jan Deppe[1,2], Christoph Becker[1,2], Ludwig Mathey[1,2,3], and Klaus Sengstock[1,2,3] — [1]Zentrum für optische Quantentechnologien, 22761 Hamburg — [2]Institut für Quantenphysik, 22761 Hamburg — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg

Arrays of neutral atoms have evolved into a leading platform for quantum computation. Alkaline-earth-like atoms promise to overcome present limitations imposed on fault-tolerant quantum computation with its two valence electron structure and single-photon Rydberg transitions, enabling new error correction schemes [1], mid-circuit readout [2-4] and novel qubit architectures [5]. Here we present our experimental approach to building an ytterbium-based Rydberg tweezer experiment and report on the recent realization of uniform tweezer arrays as well as mobile traps for atom reconfiguration. We present a machine learning assisted two-qubit gate design [6] utilizing a hybrid-classical optimizer to construct fidelity-optimal pulse sequences for realizing CNOT gates, while assuming feasible experimental parameters. [1] Nat Commun 13, 4657 (2022) [2] Nature 622, 279284 (2023) [3] PRX Quantum 4, 030337 (2023) [4] Phys. Rev. X 13, 041035 (2023) [5] Phys. Rev. A 105, 052438 (2022) [6] arXiv 2306.08691

Q 37.38 Wed 17:00 Tent B

Optical Protocol for Generating Squeezed Coherent State Superpositions — •Elnaz Bazzazi, Roger Alfredo Kögler, Leon Reichgardt, and Oliver Benson — Department of Physics, Humboldt University Berlin, Berlin, Germany

Non-Gaussian states play a crucial role in fault-tolerant quantum computing, where the manipulation of quantum states is susceptible to errors [1]. Certain classes of non-Gaussian states, notably coherent state superpositions known as cat states, pose challenges in generation due to complexity of breeding protocols and limitations in their output state [2,3]. In this study, we explore an extension of the protocol proposed in ref [4] that makes use of squeezed states and photon number-resolving detectors as resources, demonstrating potential in generating high-amplitude squeezed cat states. Simulation results validate the efficacy of this protocol, and we suggest an experimental setup for its practical realization. This research contributes to advances in fault-tolerant quantum information processing through the generation of non-Gaussian states.

[1] Phys. Rev. A 106, 022431 (2022).
[2] Phys. Rev. A 103, 013710 (2021).
[3] Opt. Express 31, 12865-12879 (2023).
[4] Phys. Scr. 97 115002 (2022).

Q 37.39 Wed 17:00 Tent B

Towards time-bin entangled photon cluster states — •Siavash Qodratipour, Thomas Häffner, and Oliver Benson — Humboldt-Universität zu Berlin, Institut für Physik, AG Nanooptik, Berlin, Germany

Single photons are ideal carriers of quantum information due to the lack of interaction with each other. However, manipulating and controlling them for quantum computing becomes a difficult task. One-way quantum computation [1] overcomes this challenge by avoiding non-linear two-qubit interaction and instead uses highly entangled states called ”cluster states”. Together with single qubit measurements and feed-forward a scalable universal quantum computer can be implemented [2]. The aim of our research is to realize a cluster state by fusion of few photon qubits which are time-bin encoded (early and late time-bins) in optical fibres. In this presentation, we will report on the generation of time-bin entangled photon pairs at 1560 nm and the subsequent characterization of the energy-time and time-bin entanglement by two photon interference [3]. We will also outline how we implement interferometric phase stability and arbitrary phase point control which are necessary to achieve a reproducible and deterministic interference. Scalability of our approach will be discussed as well.

References:
[1] Raussendorf, R. et al. Phys. Rev. Lett. 86, 5188-5191. (2001).
[2] Lu, CY. et al. Nature Phys 3, 91-95 (2007).
[3] Tanzilli, S. et al. Eur.Phys. J. D 18, 155-160 (2002).

Q 37.40 Wed 17:00 Tent B

Towards a quantum gas microscope with programmable lattices — •Sarah Waddington, Isabelle Safa, Marvin Holten, and Julian Léonard — Atominstitut TU Wien, Vienna, Austria

Cold atoms in optical lattices are a powerful platform for investigating and simulating a wide range of physical phenomena relevant to areas from condensed matter to quantum information. Our poster will describe the ongoing design and development of a quantum gas microscope capable of operation with Li6 (fermionic) or Li7 (bosonic) in a reconfigurable lattice potential with site-resolved state preparation, evolution, and readout. The setup is optimized to reach sub-second cycle times by removing the transport step and implementing advanced cooling techniques.

Potential avenues of research for our new project include simulating and investigating phases of matter predicted by the Fermi-Hubbard model, fractional quantum Hall phases, and ’frustrated’ systems with unconventional lattice shapes.

Q 37.41 Wed 17:00 Tent B

Optical Ising model simulations with caesium vapor cells — •Kilian Junicke[1], Elizabeth Robertson[1,2], Mingwei Yang[1,2], Inna Kwiatkowski[2,3], and Janik Wolters[1,2] — [1]Technische Universiät Berlin, Institute for Optics and Atomic Physics, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Rutherfordstr. 2, 12489 Berlin, Germany — [3]TU Berlin, Institut für Luft und Raumfahrt

Several computationally hard optimization problems can be mapped to finding the ground state of an Ising model [1]. Simulating Ising models optically promises speed increases [2]. Building an optical Ising machine then raises the question of how to simulate the spin states [3].

Here we present a scheme for simulating an Ising model using the ground states of cesium vapor at room temperature. We present methods for implementing positive and negative interactions using a measurement and feedback strategy. In the system electromagnetically induced transparency acts as a frequency transducer. We initialize the system and allow it to evolve by executing a series of pump probe operations on spatially multiplexed regions of an atomic vapor cell until a ground state solution is found.

[1] Lucas, A. Ising formulations of NP problems. Front. Phys. 2, 5 (2014).
[2] McMahon, P.L. Physics of optical computing. Nat Rev Phys 5, 717-734 (2023).
[3] Böhm et al. Poor man’s coherent Ising machine for optimization. Nat Commun 10, 3538 (2019).

Q 37.42 Wed 17:00 Tent B

Graph states generation from one and two atoms in an optical cavity — Philip Thomas, •Leonardo Ruscio, Olivier Morin, and

Gerhard Rempe — Max-Planck-Institut of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

Given the importance of multiphoton graph states in quantum computation and communication, their experimental demonstration is an important step towards the realization of e.g measurement based quantum computation. In our work we used single rubidium atoms trapped in the center of a Fabry-Perot cavity to grow photonic graph states. With a single atom we implemented a deterministic protocol to efficiently generate Greenberger-Horne-Zeilinger (GHZ) states and linear cluster states up to 14 and 12 photons respectively, with fidelity greater than of 76(6)% and 56(4)% [1]. Thanks to an overall single photon efficiency of 43% we collected these large states at a rate of about one coincidence per minute. Using two atoms we demonstrated the generation of more complex graphs, such as tree and ring states, exploiting an entangling mechanism based on the simultaneous emission and subsequent interference of two photons in the cavity mode [2]. Starting with two independent GHZ states we produced a tree composed of eight qubits with a lower bound fidelity of 69%. Furthermore, fusing a linear cluster states with two entangling operations we also obtained rings of six and eight qubits.

[1] P. Thomas *et al.*, Nature **608**, 677*681 (2022).
[2] P. Thomas *et al.*, Under review (2024)

Q 37.43 Wed 17:00 Tent B

Exploring the stability and performance of integrated linear optical networks for photonic quantum computing — •Cheeranjiv Pandey, Federico Pegoraro, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

In recent years, photonic quantum computing has emerged as a highly promising platform. This is particularly evident in the context of demonstrating quantum advantage in noisy intermediate-scale quantum (NISQ) computing, as explored in tasks like Boson Sampling. However, the success of many such computations relies on the ability to accurately implement arbitrary unitary transformations on input quantum states. Previous work has demonstrated the feasibility of implementing arbitrary unitary transformations using an array of linear optical elements, such as beam splitters and phase shifters. This insight led to the conceptualization of a multi-port interferometer, a versatile network that can be programmed for implementing any unitary transformation between input and output channels. The accuracy and stability of these transformations on multi-port interferometers is crucial for effective quantum algorithms. Our ongoing research explores the stability and performance of programmed unitary operations in commercially available multi-port interferometers, with the aim to investigate their suitability for photonic quantum computing.

Q 37.44 Wed 17:00 Tent B

Ion trap architectures for enhanced qubit connectivity — •Marco Valentini[1], Martin van Mourik[1], Friederike Butt[4], Matthias Dietl[1,2], Jakob Wahl[1,2], Michael Pfeifer[1,2], Marco Schmauser[1], Bassem Badawi[1], Philip Holz[3], Clemens Rössler[2], Markus Müller[4], Thomas Monz[1,3], Philipp Schindler[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Alpine Quantum Technologies GmbH, 6020 Innsbruck, Austria — [4]Institute for Quantum Information, RWTH Aachen University, 52074 Aachen, Germany

We investigate scalable ion trap architectures for quantum computing, where independent ion strings are located in distinct lattice sites (or potential wells) in a 2D array of RF traps. Distinct ion strings are coupled via their dipole-dipole interaction. Full 2D connectivity is achieved tuning the distance between adjacent potential wells along two orthogonal directions: One direction (axial) is achieved controlling DC voltages, and the other (radial) controlling RF fields. In this work we demonstrate the building blocks of such an architecture using two surface ion traps. With the first, we demonstrate DC shuttling-based well-to-well coupling rates up to 40 kHz, and phonon exchange between ion strings at the quantum level. With the second, we characterize transport of ions along the radial direction, and measure well-to-well coupling rates up to 15 kHz. These results provide an important insight into the implementation of fully controllable 2D ion trap lattices, and pave the way to the realization of 2D logical encoding of qubits.

Q 37.45 Wed 17:00 Tent B

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

Today's IT infrastructure is threatened e.g. by quantum computers implementing Shor's algorithm. Quantum key distribution (QKD) offers a method to make this infrastructure resilient against such future attacks. While various QKD setups have been tested relying on numerous different protocols, most systems do not consider scaling beyond more than two users. We report on a phase-time coding protocol based quantum key hub. The star-shaped layout of our network with an entangled photon pair source as a central untrusted node allows scaling to more than 100 users. We demonstrate the feasibility of a city-wide network by showing results from experiments with parties spatially distributed in separate buildings connected via field-deployed fiber. During a measurement our system is able to generate real-time secure keys, with one of two implemented error-correction algorithms. Furthermore, we demonstrate the plug-and-play flexibility and robustness of our setup allowing for different fiber distances, connected parties and long-time operation over several hours.

Q 37.46 Wed 17:00 Tent B

Coupling of photonic crystal fibers to nonlinear waveguides for quantum frequency conversion — •Felix Rohe, Marlon Schäfer, Tobias Bauer, David Lindler, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

Quantum frequency conversion to the low-loss telecom bands is a key enabling technology for long-range fiber-based quantum networks. While many current devices use free space coupling to channel waveguides [1,2], for real world applications a more robust and compact design is desirable. Hence, direct butt-coupling of optical fibers to channel waveguides poses an interesting alternative.
Here, we investigate coupling of solid-core photonic crystal fibers (PCF) to periodically poled lithium niobate waveguides. PCF are promising candidates for use in quantum frequency conversion due to their ability to simultaneously guide waves with a large difference in wavelengths in the fundamental mode, which is crucial to spatially overlap the signal photons and the mixing wave. We show first results regarding coupling and conversion efficiencies.

[1] Bock, M. et al., Nat Commun 9, 1998 (2018)
[2] Schäfer, M. et al., Adv Quantum Technol. 2023, 2300228

Q 37.47 Wed 17:00 Tent B

From Nonlinear Frequency Conversion towards Quantum Frequency Conversion — Anica Hamer[1], •Priyanka Yashwantrao[1], Alireza Aghababaei[1], Frank Vewinger[2], and Simon Stellmer[1] — [1]Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany — [2]Institut für Angewandte Physik, Wegelerstraße 8, Universität Bonn

Quantum networks, as envisioned for quantum computation and quantum communication applications, are often based on a hybrid architecture. Such a layout may include solid-state emitters, network nodes based on single or few atoms or ions, and photons as so-called flying qubits. This approach requires an efficient and entanglement-preserving exchange of photons between the individual components and so involves frequency conversion of the photon.

We have established two different platforms to convert individual photons between wavelengths that are relevant for qubit platforms.

The first platform is based on nonlinear crystals and converts photons from 853 nm (InAs/GaAs QDs) to 370 nm (Yb^+ ions).

The second platform is based on CSRS and CARS in dense molecular hydrogen gas. We have demonstrated conversion between 434 nm (F donors in ZnSe) to 370nm (Yb^+ ions) and between 863 nm (InAs/GaAs QDs) and the telecom O-band. We will present first steps towards integrated frequency conversion in gas-filled hollow-core fibers.

Q 37.48 Wed 17:00 Tent B

PIC based Entangled Photon Pair Source using Spontaneous Four-Wave-Mixing and Pulsed PDH-Locking — •Maximilian Mengler, Jakob Kaltwasser, Erik Fitzke, and Thomas Walther — TU Darmstadt, Institute for Applied Physics, 64289 Darmstadt

For many applications, such as quantum key distribution (QKD), entangled photon pairs are a necessity. We use the process of spontaneous four-wave-mixing to create these pairs within microring resonators on silicon nitride photonic integrated circuits (PICs). Results regarding, e.g. pair generation rate and coincidental-over-accidental ratio obtained from two distinct PICs with different layouts, specifications, and waveguide geometries will be presented and compared. As the PICs are intended as sources for our time-bin based QKD-system, the PDH technique used to lock the microring resonators to the pump light was adapted for operation with pulsed light.

Q 37.49 Wed 17:00 Tent B

High-performance imaging of nanophotonic structures in cryogenic envoirment — •Timo Eikelmann[1], Donika Imeri[1,2], Rikhav Shah[1], Lasse Irrgang[1], Mara Brinkmann[1], Tuncay Ulas[1], Konstantin Beck[1], Lennart Manthey[1], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Quantum networks require long coherence times, good interaction between atoms and photons, and strong interaction between qubits. Silicon vacancy centers within a nanophotonic diamond cavity are promising in this field. These nanophotonic structures are essential for light-matter interaction and efficient coupling to the silicon center. Structures are approximately 10 micrometers long and 500 nm wide and placed inside a cryostat to cool them down to around 0.1 Kelvin. Creating a high-performance imaging system inside a cryostat poses challenges. The imaging system must be placed partially inside the cryostat and partially outside and therefore is over 2 meters long. We implement an 8f imaging system and a pair of galvanometer-driven mirrors to scan a focused laser beam across the nanophotonic structure. This enables high-performance imaging, the scanning of a desired area with a laser in a short time and provides flexibility in imaging the given structures. High-resolution imaging enables precise coupling between nanophotonic structures and optical fibers, enabling research of efficient fiber-coupled quantum network nodes.

Q 37.50 Wed 17:00 Tent B

An improved DM-CV-QKD system for metropolitan fiber links — •Stefan Richter[1,2], Hüseyin Vural[1,2], Jan Schreck[1,2], Kevin Jaksch[1,2], Ömer Bayraktar[1,2], Thomas Dirmeier[1,2], Wenjia Elser[1,2], Dominique Elser[1,2], and Christoph Marquardt[1,2] — [1]Lehrstuhl für Optische Quantentechnologien, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Max-Planck-Institut für die Physik des Lichts, 91052 Erlangen, Germany

Continuous-variable quantum key distribution (CV-QKD) is a key building block for the quantum-safe encryption schemes needed to protect sensitive communications against the growing threat of many-qubit quantum computers in the coming decades. We present our prototype of a CV-QKD system for metropolitan fiber optical links based on the discrete modulation (DM) of coherent states and compare it to an earlier iteration. We propose solutions to several technical challenges of the implementation, including procedures for automatic working-point stabilization, calibration, as well as phase recovery and tracking. Asymptotic keyrate estimates as a performance metric are discussed in the context of additional constraints imposed by the error correction implemention.

Q 37.51 Wed 17:00 Tent B

Towards Quantum Memories in Noble-Gas Nuclear Spins with Alkali Metal Vapour as Optical Interface — •Norman Vincenz Ewald[1,2], Tianhao Liu[2,5], Alexander Erl[1,2], Luisa Esguerra[1,3], Wolfgang Kilian[2], Jens Voigt[2], Denis Uhland[4], Ilja Gerhardt[4], and Janik Wolters[1,3] — [1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin — [2]Physikalisch-Technische Bundesanstalt, FB 8.2 Biosignale, Berlin — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin — [4]Leibniz University Hannover, Institute of Solid State Physics, Hannover — [5]Tragically deceased on 22 July 2023.

Quantum memories with storage times well beyond 1 s will spawn manifold applications in quantum communication, e.g. as quantum token for authentication. We present our first steps towards a quantum memory with long storage time in a mixture of the noble gas ^{129}Xe and an alkali metal vapour of ^{133}Cs. A custom glass cell at about room temperature contains both species and is placed inside a table-top magnetic shield. Information will be stored in the collective excitation of nuclear spins of ^{129}Xe, which exhibit hours-long coherence times [1]. ^{133}Cs serves as optical interface for signal photons, which we store in a collective spin excitation using EIT [2]. Coherent information transfer to the noble gas spins is based on spin-exchange collisions and will be controlled by synchronisation of Larmor precession [3].

[1] C. Gemmel et al., *Eur. Phys. J. D* **57**, 303–320 (2010). [2] L. Esguerra et al., *Phys. Rev. A* **107**, 042607 (2023). [3] O. Katz et al., *Phys. Rev. A* **105**, 042606 (2022).

Q 37.52 Wed 17:00 Tent B

Simulation of Cluster state generation process with time-bin protocol — Ruolin Guan[1], •Fei Ding[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany

The on-demand generation of multi-entangled photons is an attractive goal for the realization of quantum communication networks. Photonic Cluster State, is a promising multi-entangled state because they are specifically prepared for measurement-based quantum computation. Here, we propose to develop a simulation method for generating multi-photon states, particularly linear cluster states with time-bin protocol. Additionally, we utilize a local measurement approach to simulate the measurement process.

Q 37.53 Wed 17:00 Tent B

Multiphoton interference in multidimensional systems — •Felix Twisden, Jan Sperling, and Polina Sharapova — Paderborn University, Warburger Strasse 100, 33098 Paderborn

Multidimensional entanglement is a key source for many quantum applications, such as quantum computing, quantum communication and quantum simulation [1]. Therefore, we investigate in this work a four-channeled quantum optical system, which is driven by two spontaneous parametric down-conversion (SPDC) sources (each emitting two photons), in order to characterize the photons via coincidence probability. The system represents an integrated quantum circuit with four channels, based on the platform material lithium niobate. The optical components can be adjusted in such a way that the polarization of the photons can be set individually. Furthermore, a time delay between the four photons can be introduced. In this system, two photon pairs (four photons) are generated by an independent SPDC-source and is therefore characterized by a spectrally entangled frequency distribution. The main goal is to investigate the coincidence probability for the described four photon case of the multichannel and multifrequency system regarding different configurations of the optical elements.

[1] J. Wang, S. Paesani, Y. Ding, R. Santagati, P. Skrzypczyk, A. Salavrakos, J. Tura, R.Augusiak, L. Mančinska, D. Bacco, et al., Multidimensional quantum entanglementwith large-scale integrated optics, Science360, 285*291 (2018).

Q 37.54 Wed 17:00 Tent B

Photonic integrated circuits for phase-encoded prepare-and-measure QKD on a CubeSat — •Joost Vermeer[1,2], Jonas Pudelko[1,2], Kevin Günthner[1,2], and Christoph Marquardt[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany

In the past decade several projects have been started to develop satellite based quantum key distribution (QKD) systems and avoid the range limitations of fiber based QKD systems. The cost of these systems is for a large part determined by the size, weight and power of the satellite. With photonic integrated circuits (PICs) one can integrate many optical components on a single chip, which opens up the possibility to implement all the optical functions necessary for QKD with reduced size, weight and power requirements.

In this work, we will present our optical CubeSat payload for the QUBE-II mission. It will perform phase encoded prepare-and-measure QKD with weak coherent states using an Indium-Phosphide transmitter PIC. We discuss the requirements for this transmitter PIC and compare different PIC design approaches to investigate which one can best fulfill these requirements.

Q 37.55 Wed 17:00 Tent B

Characterization of second order noise processes in waveguide-based quantum frequency converters — •Ann-Kathrin Müller, Markus Struckmann, Florian Elsen, and Constantin Leon Häfner — Chair for Laser Technology, RWTH Aachen University

Quantum frequency converters (QFCs) are photonic interfaces that convert the photons emitted by qubits to the low-transmission-loss telecom bands for fiber-based quantum communication. They can be realized using difference-frequency-generation (DFG) with a strong laser field in periodically poled nonlinear materials, e.g. in a waveguide.

The aim is to maximize conversion efficiency whilst minimizing noise generation. Long-wavelength-pumped QFCs in which the strong light field is the lowest frequency component in the DFG process are theoretically considered quasi-noise-free.

However, during this work, noise characterization of a long-wavelength-pumped QFC from 856.7 nm to 1527.7 nm identified second harmonic generation (SHG) of the strong laser field with subsequent spontaneous parametric downconversion as a prominent noise source. Specifically, SHG-power in the milliwatt-regime was measured, showing the relevance of two-staged effects to noise in long-wavelength-pumped QFCs. This study advances the understanding of noise generation in QFCs, offering insights into the implications for QFC design and critical considerations for optimizing quantum networks.

Q 37.56 Wed 17:00 Tent B

Singular modes of light in dynamic random media — •David Bachmann[1], Mathieu Isoard[1,2], Giacomo Sorelli[1,3], Vyacheslav Shatokhin[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut der Albert-Ludwigs-Universität Freiburg — [2]Laboratoire Kastler Brossel, Paris, France — [3]Fraunhofer Institute for Optronics, Ettlingen, Germany

Wave propagation through random continuous media is an important fundamental problem with applications ranging from remote sensing to quantum communication. We refine the methods for accurate numerical simulation and table-top experiments of such media by introducing novel hybrid phase screens. Within this framework, we investigate the effects of disorder on structured light and show how instantaneous spatial singular modes of light offer improved high-fidelity signal transmission in dynamically evolving media compared to standard encoding bases. We show that power-law spectra such as the atmospheric Kolmogorov spectrum induce a subdiffusive algebraic decay of transmitted power as a function of time.

Q 37.57 Wed 17:00 Tent B

TOWARDS CONSUMER-LEVEL QUANTUM-SECURE CRYPTOGRAPHY ENTANGLEMENT-BASED SHORT-RANGE QUANTUM-KEY-DISTRIBUTION — •Luca Graf[1,2,3], Henning Mollenhauer[1,2,3], Till Appel[1,2,3], Daniel Tippel[1,2,3], Pius Gerisch[1,2,3], and Ralf Riedinger[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Deutschland — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany — [3]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Deutschland

Over the last years various methods of quantum key distribution (QKD) have been developed. Long distance implementations remain challenging due to the exponential loss of photons in quantum channels. A possible solution is hybrid cryptography, with key distribution over short distance, followed by quantum-secure classical encryption over long distance. Short-range QKD allows for exchanging an information-theoretically secure root-of-trust that is stored on two end modules. This root-of-trust is employed to generate encryption keys through classical rekeying algorithm. In this approach it is possible to spatially separate the end modules and communicate over existing communication infrastructure since no quantum channel required after initialization. We present an experimental setup for short-range QKD with low-cost end modules that has the potential to be made compact enough to be implemented with semiconductor electronics.

Q 37.58 Wed 17:00 Tent B

Machine learning improved search for nitrogen-vacancy colour centres with long coherence times — •Ricky-Joe Plate, Jan Thieme, and Kilian Singer — Universität Kassel, Kassel, Germany

Nitrogen-vacancy colour centres are offering promising qubits for room temperature quantum information processing [1]. The quality of the qubits varies over a typical diamond sample and finding colour centres with long coherence times can be a time-consuming process in the lab. Here we present the architecture of a machine learning-based network [2] that allows for an automated search and characterization of optimal colour centres. An open-source implementation based on high-speed c++ code will be presented, that allows easy integration of custom improvements to the code base.

[1]: Maurer, P.C., Kucsko, G., Latta, C. (2012): Room-Temperature Quantum Bit Memory Exceeding One Second, in: Science Vol 336 Issue 6086, pp. 1283-1286, doi: 10.1126/science.1220513. [2]: Jiang, X., Hadid, A., Pang, Y., Granger, E. und Feng, X. (Hrsg.) (2019) Deep learning in object detection and recognition. Singapore: Springer.

Q 37.59 Wed 17:00 Tent B

A compact WGMR-based source optimized for coupling to an ion in a deep parabolic mirror — Sheng-Hsuan Huang[1,2], •Thomas Dirmeier[1,2], Martin Fischer[1,2], Markus Sondermann[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[2,1] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

As part of the BMBF QuNET initiative, it is planned to demonstrate the coupling of a mobile node containing a SPDC source to a stationary ion trap.

Cavity-assisted SPDC sources have been known to allow for the efficient coupling to atomic transitions. They often require additional spectral filtering cavities, thus leading to a higher experimental complexity. However, optical whispering gallery mode resonators (WGMR) have been proven to be compact, efficient and single mode sources of e.g. squeezed states or heralded single photons which can be coupled well to alkali metal vapours [1-3].

In our presentation, we discuss the concept and progress on the realization of a compact WGMR source that is specifically tailored to the $D_{3/2} \Leftrightarrow D[3/2]_{1/2}$ transition at 935 nm of $^{174}Yb^+$. We also highlight the challenges faced while developing a photon-ion-coupling experiment for a mobile platform, in this case an airplane.

[1]A.Otterpohl, et.al., Optica 6, 1375-1380 (2019)
[2]G.Schunk, et.al., Journal of Modern Optics 63 (2016)
[3]M.Förtsch, et.al., Physical Review A 91(2) 023812 (2015)

Q 38: Poster IV

Time: Wednesday 17:00–19:00 Location: KG I Foyer

Q 38.1 Wed 17:00 KG I Foyer

New Magnetically Levitation System for Magnetometry — •Changhao Xu[1,2], Wei Ji[1,2], and Dmitry Budker[1,2,3] — [1]Helmholtz Institute Mainz, Mainz, Germany — [2]Johannes Gutenberg University, Mainz, Germany — [3]Department of Physics, University of California at Berkeley, Berkeley, California 94720-7300, USA

In this work, we attempt to provide a novel magnetometer operable at room temperature. We firstly achieved stable levitation of magnets smaller than 1mm in size at room temperature using diamagnetic levitation techniques. For the levitated magnets, their rotational degrees of freedom are sensitive to external magnetic field strengths with low dissipation. Through the application of optical lever techniques, we have realized high-sensitivity measurements of the rotational dynamics of the levitated magnets. After suppressing factors such as magnetic field noise, air fluctuation, laser-induced thermal damage, and system vibrations, we have currently achieved a sensitivity of 1pT/Hz^1/2 for magnets with a size of 0.5mm.

Q 38.2 Wed 17:00 KG I Foyer

GHZ-bandwidth four-wave mixing in a thermal rubidium vapor using the 6P intermediate state — •Max Mäusezahl[1], Felix Moumtsilis[1], Moritz Seltenreich[1], Jan Reuter[2,3], Haim Nakav[4], Hadiseh Alaeian[5], Harald Kübler[1], Matthias Müller[2], Charles Stuart Adams[6], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Forschungszentrum Jülich GmbH, PGI-8, Germany — [3]Universität zu Köln, Germany — [4]Weizmann Institute of Science and AMOS, Israel — [5]Departments of Electr. & Computer Engin. and Physics & Astronomy, Purdue University, USA — [6]Department of Physics, Joint Quantum Centre (JQC), Durham University, UK

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

Here we report on the current state, technical challenges, time resolved nanosecond pulsed four-wave mixing, GHz Rabi cycling and photon statistics involving the 40S Rydberg state. Using an updated electrical pulse system and detectors we can increase photon generation and detection efficiency, while exploring the effects of the novel excitation scheme experimentally and numerically. The MHz repetition rate and excitation timescales also pave the way towards fast optimal control methods for high fidelity Rydberg logic gates.

Q 38.3 Wed 17:00 KG I Foyer

Gyroscopy with ensemble NV centers in diamond — •Muhib Omar[1,2], Joseph Shaji Rebeirro[1,2], Dmitry Budker[1,2,3], and Arne Wickenbrock[1,2] — [1]Helmholtz-Institut, GSI Helmholtzzentrum für Schwerionenforschung, 55128 Mainz, German — [2]Johannes Gutenberg-Universität Mainz, 55128 Mainz, German — [3]Department of Physics, University of California, Berkeley, California 94720, USA

A rotation sensor protocol utilising the nitrogen nuclear spin in the Nitrogen-Vacancy center (NV) system in diamond is proposed. The nuclear spin state preparation method employed, consisting of a single green laser pulse and a microwave pulse, is to date the shortest pulse sequence employable for gyroscopic sensing using nuclear spins in diamond at arbitrary fields. Field dependence of lower magnetic bias field dynamical nuclear spin polarisation sequences is studied.

Q 38.4 Wed 17:00 KG I Foyer

Magnetometry and Thermometry with NV centers in a seeded optical cavity — •Florian Schall[1], Felix A. Hahl[1], Lukas Lindner[1], Alexander Zaitsev[2], Takeshi Ohshima[3], and Jan Jeske[1] — [1]Fraunhofer Institute for Applied Solid State Physics, Freiburg im Breisgau, Germany — [2]College of Staten Island, New York, USA — [3]National Institutes for Quantum Science and Technology, Gunma, Japan

To measure magnetic fields and temperatures with NV centers in diamond, their spin-dependent fluorescence is usually monitored in an optically detected magnetic resonance (ODMR) measurement. A different approach is the concept of laser threshold magnetometry (LTM), that uses the NV centers as a laser medium. Recently researchers have demonstrated the magnetic field dependence of the stimulated emission from NV centers in a high-finesse optical cavity using a seeding laser. Based on these results we determined the strength and orientation of external magnetic fields created by a permanent magnet. Due to the high finesse of the optical cavity, we achieved high contrasts and output powers in the ODMR measurements. We also investigated the influence of laser and microwave power on diamond temperature. By specifically varying the diamond temperature, we successfully verified the well-known temperature dependence of the zero-field splitting of the NV center. Our results show the first vectorial magnetic field determination with a setup based on LTM. The investigation of the laser-induced temperature changes is highly relevant for a future integration of the setup.

Q 38.5 Wed 17:00 KG I Foyer

Progress towards a fiber-based cold atom source in the meter range — •Marcus Malki, Viet Hoang, Thomas Halfmann, and Thorsten Peters — TU Darmstadt, Darmstadt, Germany

Quantum technologies require controlled interactions with quantum systems that are otherwise isolated from the incoherent environment. In the case of neutral atoms or ions inside a vacuum system this means efficient shielding of the quantum systems from their source, which often is a hot oven. One solution to this problem is a flexible, cold source of neutral atoms.

We here report on our progress towards realizing such a source by implementing a hollow-core fiber (HCF) guide for cold ^{87}Rb atoms in the meter range. The guide is based on an optical dipole trap propagating through the HCF to minimize collisions of the cold atoms with the fiber wall.

We will discuss various considerations regarding the maximum guiding distance, such as background pressure inside the HCF, fiber bending radius, and parametric heating. We will also present first measurements of the HCF loading phase from atoms provided by a dark-line magneto-optical trap and discuss how the number of atoms, their temperature and velocity can be probed inside a HCF.

Q 38.6 Wed 17:00 KG I Foyer

Temperature dependence of charge conversion during NV-center relaxometry — •Isabel Cardoso Barbosa, Jonas Gutsche, Stefan Dix, Dennis Lönard, and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Temperature-dependent nitrogen-vacancy (NV)-center relaxometry is an established tool to characterize paramagnetic molecules near a sensing diamond. However, charge conversion between the negatively charged NV^- and the neutrally charged NV^0 impedes these pulsed-laser measurements and influences the results for the T_1 time. While the temperature dependence of the NV centers' T_1 time is well-studied, contributions from temperature-dependent charge conversion during the dark time τ may further affect the measurement results. We combine temperature-dependent relaxometry and fluorescence spectroscopy to unravel the temperature dependence of charge conversion in nanodiamond for biologically relevant temperatures. While we observe a decrease of the T_1 time with increasing temperature, charge conversion remains unaffected by the temperature change. These results allow the temperature-dependent performance of T_1 relaxometry without further consideration of temperature dependence of charge conversion.

Q 38.7 Wed 17:00 KG I Foyer

Stable Zerodur based optical system for the MAIUS-2 mission — •Sören Boles[1], Moritz Mihm[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and the MAIUS Team[1,2,3,4,5,6] — [1]Johannes Gutenberg Universität Mainz — [2]ILP, Universität Hamburg — [3]Institut für Physik, HU-Berlin — [4]IQO, Leibniz Universität Hannover — [5]ZARM, Universität Bremen — [6]FBH, Berlin

Launched in December 2023, the MAIUS-2 mission investigates BEC-mixtures of Rb and K in microgravity environment on a sounding rocket flight. To assure stable performance of the optical system under the harsh launch conditions, fiber-coupled optical benches were manufactured based on the glass ceramic Zerodur, a material which excels in having a very low coefficient of thermal expansion (CTE), as well as a high mechanical strength. Successful implementation of this optical technology was shown in various missions, such as FOKUS, KALEXUS, as well as its predecessor MAIUS-1.
MAIUS-2 represents new challenges to the optical technology, since light to manipulate both atomic species has to be intensity controlled, pulse-shaped and fiber-coupled to realize the experimental goals.
In this submission, we will present the performance of the Zerodur optical technology during the launch and flight of the MAIUS-2 mission.
MAIUS is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economic Affairs and Climate Action (BMWK) under grant numbers 50WP1433 & 50WP2103.

Q 38.8 Wed 17:00 KG I Foyer

(Near) zero-field cross-relaxation features for diamond magnetometry — •Omkar Dhungel[1,2], Till Lenz[1,2], Mariusz Mrózek[3], Muhib Omar[1,2], Joseph Shaji Rebeirro[1,2], Wojciech Gawlik[3], Adam Wojciechowski[3], Viktor Ivady[4,5,6], Adam Gali[7,8], Arne Wickenbrock[1,2], and Dmitry Budker[1,2,9] — [1]Helmholtz-Institut Mainz, GSI, 55128 Mainz, Germany — [2]JGU Mainz, 55128 Mainz, Germany — [3]Jagiellonian University, Faculty of Physics, Astronomy and Applied Computer Science, Lojasiewicza St. 11, 30-348 Krakow, Poland — [4]Department of Physics of Complex Systems, ELTE Eötvös Loránd University, Egyetem tér 1-3, H-1053 Budapest, Hungary — [5]MTA-ELTE Lendület *Momentum* NewQubit Research Group, Pázmány Péter, Sétány 1/A, Budapest,1117, Hungary — [6]Department of Physics, Chemistry and Biology, Linköping University, 581 83 Linköping, Sweden — [7]Wigner Research Centre for Physics, P.O. Box 49, H-1525 Budapest, Hungary — [8]BUTE, Institute of Physics, Department of Atomic Physics, Müegyetem rakpart 3., 1111 Budapest, Hungary — [9]Department of Physics, UC, Berkeley, California 94720-300, US

We study zero-field cross-relaxation features of negatively charged nitrogen-vacancy (NV) center ensembles in diamond. This feature holds promise for magnetometry applications where either the microwaves or the bias magnetic field used in conventional NV center magnetometry disturb the system under study; for example, the study of high-temperature superconductors, zero- to ultralow-field (ZULF) NMR, investigation of biological samples, and magnetic materials.

Q 38.9 Wed 17:00 KG I Foyer

Ion trap chips on dielectric substrates for double-well coupling experiments — •Michael D.J. Pfeifer[1,2], Simon Schey[1,3], Matthias Dietl[1,2], Fabian Anmasser[1,2], Jakob Wahl[1,2], Marco Valentini[2], Martin van Mourik[2], Thomas Monz[2], Fabian Laurent[1], Clemens Rössler[1], Yves Colombe[1], and Philipp Schindler[2] — [1]Infineon Technologies Austria AG, Villach, Austria — [2]University of Innsbruck, Innsbruck, Austria — [3]Stockholm University, Stockholm, Sweden

We report on surface ion trap chips, industrially fabricated at Infineon Technologies [1,2], that are capable to generate a two-well potential for trapping ions. The chips are designed for investigating rf shuttling in the large separation and in the coupling regimes as element of a scalable architecture [1]. The optimization of the design parameters of a surface ion trap in the rf coupling regime with optimal ion height and ion-ion distance is discussed.

The dielectric substrates Fused Silica and Sapphire are used in the fabrication of the chips. The status of the microfabrication on these materials is discussed, with a focus on optical and electric properties, as well as on wafer bow.

[1] Ph. Holz, S. Auchter et al., Adv. Quantum Technol. 3, 2000031 (2020)

[2] S. Auchter, C. Axline et al., Quantum Sci. Technol. 7, 035015 (2022)

Q 38.10 Wed 17:00 KG I Foyer

Microscopy Setup for Optical Measurements of Distances between Nanodiamonds and Microwave-Antennas — •Oliver Beiersdorf, Stefan Dix, Dennis Lönard, Isabel Barbosa, and Artur Widera — Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Due to their properties, negatively charged nitrogen-vacancy (NV) centers in nanodiamonds are well-known in the field of magnetometry. In these quantum systems, spin transitions can be induced by resonant microwave pulses and measured by fluorescence after laser excitation.

In this work, a reflected light microscopy setup for nanodiamonds was built, including illumination and excitation of a sample positionable with an accuracy of about 100 nm, a camera setup, and a fluorescence detection unit. It further allows to freely position optical fibers over the sample with an accuracy of about 1 μm.

In this way, we want to quantify the dependence of the rabi-oscillations of NV centers on the distance of a fiber-based endoscope with a silver direct-laser-written structure for microwave emission next to a fiber facet that can be used for excitation. By successfully determining this dependence, we aim to validate the suitability of NV diamonds as quantum sensors not only for magnetometry but also for distance determination, ultimately enabling multifunctional NV-based sensors.

Q 38.11 Wed 17:00 KG I Foyer

Real-world NV-center vector magnetometry of a 3D coil system — •Dennis Lönard, Stefan Dix, Isabel Barbosa, and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

The nitrogen-vacancy (NV) color center in diamond is an essential platform for magnetic field sensing for technical and biological applications. One major advantage is that the spin state of the NV-center can be read out optically via fluorescence. Observing the Zeeman-splitting of four independent NV axes in one diamond then enables full vectorial magnetometry. The signal detection of the NV fluorescence can be substantially improved with lock-in amplification. However, discussions of magnetic field sensitivity are often limited to artificially engineered lab conditions. Technical difficulties that arise when NV magnetometry is to be performed in unknown magnetic fields are often disregarded.

Here, we present a real-world measurement of the vector magnetic field of a 3D coil system, used in a quantum gases experiment. Our sensor exhibits magnetic field sensitivities down to 200nT/rt(Hz) with bandwidths of up to 100Hz. Thus showing the improvements NV center magnetometry can deliver over conventional instruments like Hall-sensors. Signal-to-Noise ratio and magnetic field sensitivity can be further improved with balanced photodiode detection techniques.

Q 38.12 Wed 17:00 KG I Foyer

Optimizing efficiencies in time-multiplexed photonic quantum walks — •Philip Held, Vincent Borlisch, Federico Pegoraro, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Germany

Quantum walks function as essential means to implement quantum simulators, allowing one to study complex quantum processes that often cannot be directly accessed in the laboratory. Time-multiplexed photonic quantum walks offer the possibility to build easily scalable systems. Here the position space of the walk is mapped to temporal bins and physical elements of the setup are used time and again. Experimentally this is implemented by realizing a looped structure, such that each step is implemented by one roundtrip through the setup. Thus, the overall losses - wich constitute the main limitation of the system - are mainly determined by the roundtrip losses that scale exponentially with the step number. In this contribution, we present a new scheme to build time-multiplexed photonic quantum walks. We were able to reduce the number of required optical components and improve the spatial mode matching of the optical paths. The new setup architecture features a smaller, compact footprint, higher long-term stability, and a reduction of losses by more than 25% compared to the original version. We now achieve a round-trip efficiency of 86%, which reduces the measurement time by an order of magnitude for a 20-step two-photon quantum walk.

Q 38.13 Wed 17:00 KG I Foyer

Nonlinear light-matter interaction based on integrated waveguides immersed in hot atomic vapor — •Annika Belz[1], Robin Klöpfer[1], Benyamin Shnirman[1,2], Xiaoyu Cheng[1], Harald Kübler[1], Charles Stuart Adams[3], Hadiseh Alaeian[4], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Germany — [2]Institut für Mikroelektronik Stuttgart (IMS-Chips), Stuttgart, Germany — [3]Department of Physics, Joint Quantum Centre (JQC) Durham-Newcastle, Durham, United Kingdom — [4]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, West Lafayette, USA

The combination of thermal atomic vapor with nano-photonic structures provides a unique platform for the manipulation of atom-photon and light induced atom-atom interactions and can exhibit large optical non-linearities, even at the single photon level.

We can further enhance these non-linearities by using slot waveguides in which we observe repulsive interactions of the atoms within the slot via an enlarged Purcell factor. Thereby we generate a medium that reaches already in this specific setting a nonlinearity on the few photon level. In order to verify the nature of the non-linearity in more detail we plan to incorporate an integrated Mach-Zehnder interferometer to access also the non-linear phase shift.

Furthermore, we present first measurements of the phase shift in a thermal atomic vapor using a fiber coupled Michelson interferometer.

Q 38.14 Wed 17:00 KG I Foyer

A miniaturized and integrated fiber-based magnetic field sensor — •Stefan Dix, Dennis Lönard, Isabel Cardoso Barbosa, Jonas Gutsche, and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

The nitrogen-vacancy (NV) center is a crucial element in measuring precise magnetic fields while also retrieving temperature information. Possible applications for this sensor range from medical surgery over the analysis of magnetic samples to current monitoring of today's electric vehicles. While other concepts for integrated sensors have been shown, ongoing miniaturization requires ever smaller yet more robust sensing devices. In this work, we developed a versatile and robust sensor platform for macroscopic handling while maintaining a compact size and including wires and optical fibers on a platform diameter of 1.25 mm. Furthermore, we use direct laser writing to fixate and couple a 15 μm-sized diamond containing NV centers to one optical fiber and create a waveguide structure between another optical fiber to excite the NV center. Thus, we separate beam paths for excitation and detection to enhance the sensitivity. Necessary antenna structures are created on the tip of an optical fiber using a silver direct laser writing process. We test our device by probing the field distribution of a magnetic-coil system with high spatial and magnetic field resolution. Our results point towards a sub-millimeter, integrated sensor for high spatial resolution vector magnetometry with a large bandwidth.

Q 38.15 Wed 17:00 KG I Foyer

Fabricating high-finesse fiber Fabry-Perot cavities for quantum simulation — •Constantin Grave, Isabelle Safa, Marvin Holten, and Julian Leonard — TU Wien - Atominstitut, Stadion-

allee 2, 1020 Wien, Österreich

Fiber Fabry-Perot cavities (FFPCs) are used in a wide spectrum of technical and scientific applications ranging from cavity quantum electrodynamics and fiber-coupled single-photon sources to new scanning microscopy techniques. We realize a highly automated fabrication facility to manufacture curved mirrors on the end-facets of optical fibers. While the curvature is shaped with a CO2 laser, the coating for the reflectivity is applied externally. In our setup a Mireau objective using white light interferometry is included, allowing us to measure the shape of the mirror during production and enabling iterative optimisation of the geometry. We expect this approach to result in small yet open FFPCs with favorable scaling properties, small mode volumes as well as high finesses. This combination of features is advantageous for the construction of compact and robust quantum-enabled devices like the currently build setup of our group, that uses an tweezer-loaded array of neutral atoms inside a FFPC.

Q 38.16 Wed 17:00 KG I Foyer

Industrial fabrication of surface ion-traps with integrated optics — •Jakob Wahl[1,2], Alexander Zesar[1], Klemens Schüppert[1], Clemens Rössler[1], Philip Schindler[2], and Christian Roos[2] — [1]Infineon Technologies Austria — [2]University of Innsbruck

Trapped ions have shown great promise as a platform for quantum computing, with long coherence time, high fidelity quantum logic gates, and the successful implementation of quantum algorithms. However, to develop trapped-ion based quantum computers from laboratory setups to practical devices for solving real-world problems, the number of controllable qubits must be increased while improving error rates. One of the major challenges for scaling trapped-ion quantum computers is the need to switch from free space to integrated optics, to achieve lower drift and vibrations of light relative to the ion, and therefore more stable and scalable ion-addressing.

At Infineon and the University of Innsbruck, we are working on the integration of optical elements in surface ion traps, which are fabricated in industrial semiconductor facilities at Infineon. We use femtosecond-laser written waveguides to guide light in a glass-block that is manufactured on the chip's surface in wafer-level processes. The integrated waveguides eliminate vibrations between optics and the ion, and therefore reduce intensity fluctuations of the laser light at the position of the ion. Moreover, integrated waveguides can enable complex light routing to multiple trapping sites and make quantum information processors more robust and more parallelizable.

Q 38.17 Wed 17:00 KG I Foyer

Edge Machine-Learning assisted Magnetometer Based on NV-Ensembles in Diamond — •Jonas Homrighausen[1], Ludwig Horsthemke[2], Jens Pogorzelski[2], Sarah Trinschek[1], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, University of Applied Sciences, Münster — [2]Department of Electrical Engineering and Computer Science

In the field of quantum sensing, particularly in magnetometry, the nitrogen-vacancy (NV) center in diamond stands out as a promising sensor material. It offers high sensitivity, exceptional spatial resolution, and wide bandwidth at room temperature, making it an ideal candidate for miniaturization and integration due to its solid-state host crystal. However, the real-time tracking of magnetic field strengths using optically detected magnetic resonance (ODMR) poses challenges, requiring sophisticated equipment such as multi-channel frequency modulated RF generators and lock-in techniques. Additionally, accurately calculating magnetic field magnitudes from transition frequencies requires various parameters like crystal orientation and internal strain parameters. To address these challenges, we propose a machine-learning assisted approach leveraging an ESP32 microcontroller as the central control and acquisition unit [1]. By performing inference on a pre-trained artificial neural network using data collected from a fiber-coupled NV ensemble, we obtain the local magnetic field magnitude at the fiber tip. By using off-the-shelf components, we present a low-cost, low-power standalone sensor device that can easily made portable.

[1] J. Homrighausen et al. (2023). Sensors 23(3), 1119.

Q 38.18 Wed 17:00 KG I Foyer

Rydberg Atom-based RF Sensors: E-field amplitude and phase-sensitive detection — •Clara Roth, Matthias Schmidt, Lara Metzger, Stephanie Bohaichuk, Chang Liu, Florian Christaller, Vijin Venu, Harald Kübler, and James Shaffer — Quantum Valley Ideas Laboratory, Waterloo, Canada, ON

We present theoretical work aimed at understanding radio frequency phase and amplitude measurement using all-optical, atom-based electric field sensors. Atom-based radio frequency field sensors have a number of applications in communications, radar and test and measurement where both phase and amplitude information are important. We apply the weak probe approximation to the Lindblad-master equation and find analytic expressions for the density matrix in steady state in several level schemes up to 5 levels where a closed loop is formed. We focus especially on the absorption coefficient and the populations of Rydberg states. With these expressions, we gain a deeper understanding of the multi-photon interference and how this applies to phase and amplitude readout in atom-based radio frequency sensors.

Q 38.19 Wed 17:00 KG I Foyer

Low Cost Prototyping and Teaching Platform for Quantum Sensing using NV Centers — •Marina Peters[1], Jan Stegemann[1], Ludwig Horsthemke[2], Matthias Hollmann[1], Nils Haverkamp[3], Stefan Heusler[3], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Münster University of Applied Sciences, Germany — [2]Department of Electrical Engineering and Computer Science, FH Münster University of Applied Sciences, Germany — [3]Institute of Physics Education Research, University of Münster

With the growing importance of quantum technology in industry and research, the need for affordable, flexible and robust laboratory experiments for prototyping and university studies is increasing. With this modular, 3D-printed, low-cost (< €250) open source experiment platform [1,2], students can learn about the principles of quantum systems using the example of NV centers in diamond. The optical components are mounted in 3D-printed cubes [3,4] that can be freely arranged on a grid. The platform presented enables experiments on magnetometry using optically detected magnetic resonance (ODMR) and lowers the threshold to access modern quantum technology. [1] www.O3Q.de [2] Stegemann, J. et al. European Journal of Physics 44 (2023), [3] Diederich, B. et al. Nature Communications11, 5979 (2020) [4] Haverkamp, N. et al. Physics Education 57 025019 (2022)

Q 38.20 Wed 17:00 KG I Foyer

Coherent control of ion motion via Rydberg excitation — •Marion Mallweger[1], Andre Cidrim[2], Harry Parke[1], Natalia Kuk[1], Robin Thomm[1], Chi Zhang[1], and Markus Hennrich[1] — [1]Stockholm University, Stockholm, Sweden — [2]Universidade Federal de São Carlos, São Carlos, Brazil

Trapped Rydberg ions are a novel approach to quantum information processing, combining qubit rotations in the ions' ground states with entanglement operations via Rydberg interaction. In the experiments presented here a trapped strontium ion was excited from the metastable 4D to Rydberg states. While for the ground state of the ion, the polarizability is negligible, for Rydberg ions it increases as $\sim n^7$. Thus, the high polarizability of the Rydberg state with respect to the ground state leads to a displaced trapping potential during the Rydberg excitation if the ion experiences an offset electric field. We explore how this trapping field displacement can be employed for coherent control of the ions' motion. We investigate this effect by performing coherent excitation of the ion to the Rydberg state by using stimulated Raman adiabatic passage (STIRAP). Repeated transitions between the ground and the Rydberg states enhances the effect of the ion displacement due to the change in trapping potential. This can be used to induce a geometric phase accumulation via the ion motion. This excitation of motional modes via Rydberg excitation and the generation of geometrical phases could be utilized for realizing a fast quantum phase gate between multiple ions.

Q 38.21 Wed 17:00 KG I Foyer

QKD with atom photon entanglement over an urban fiber link — •Jonas Meiers, Christian Haen, Max Bergerhoff, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Quantum cryptographic protocols offer physical security through no-cloning or entanglement. Following the entanglement-based quantum key distribution protocol of [1], we present our implementation of atom-photon entanglement-based quantum key distribution over a telecom fiber in a metropolitan network. The protocol requires four atomic bases as well as two photonic bases and allows us to create a quantum key with security verification via the Bell parameter. We employ the polarization entanglement between a single trapped $^{40}Ca^{+}$-ion and an emitted photon at 854 nm according to [2], generated via the $P_{3/2} \rightarrow$

$D_{5/2}$ transition. The photon is frequency-converted into the telecom band and transmitted via a 15-km long urban dark fiber across Saarbrücken. The fiber has been characterized and stabilized for the transmission of polarization-encoded qubits. Following the implementation we discuss how well the experimental data agree with the predictions from the theoretical protocol.

[1] R. Schwonnek et al., Nat. Commun. 12, 2880 (2021)
[2] M. Bock et al., Nat. Commun. 9, 1998 (2018)

Q 38.22 Wed 17:00 KG I Foyer

A Squeezed Light Interface for Silicon Vacancy Centers in Diamond — •Konstantin Beck[1], Donika Imeri[1,2], Mara Brinkmann[1], Timo Eikelmann[1], Lasse Jens Irrgang[1], Lennart Manthey[1], Sunil Kumar Mahato[1,2], Rikhav Shah[1], Roman Schnabel[1,2], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Silicon vacancy centers in diamond (SiV) have shown great potential for applications in quantum sensing and quantum communication, due to their optically addressable spin transitions and stability against noise. At temperatures below 300 mK, the SiV has a long-lived spin degree of freedom that enables its use as a qubit for quantum information applications. Integrating the properties of SiV centers with the accessibility of a fiber network operating at telecom wavelengths can enable efficient long-distance quantum communication.

We present a conceptual framework of an optical interface where we couple squeezed photons to the silicon vacancy qubit and create Gottesman-Kitaev-Preskill (GKP) states, known for their significance in error resilient quantum communication protocols. We discuss the theoretical aspects of GKP state creation as well as the experimental setup. Key aspects such as the squeezed state preparation, the diamond nanophotonic cavities hosting SiV centers and the overall architecture of the experiment are highlighted.

Q 38.23 Wed 17:00 KG I Foyer

Fast, efficient and lossless measurement of atom-photon entanglement — •Gianvito Chiarella, Tobias Frank, Pau Farrera, and Gerhard Rempe — Max Planck Institute for Quantum Optics, Garching bei München, Germany

Efficient quantum light-matter interfaces are crucial for the development of quantum networks, which allow the generation, distribution and storage of quantum states over remote locations. Two important capabilities of a quantum network node are the efficient generation of entanglement between a stationary and a flying qubit and the measurement of the stationary qubit in a fast and efficient way. Moreover it is also important that the stationary qubit is usable after its measurement. Even though these features have been shown separately in previous works, achieving them simultaneously remains a challenge. Here we report about a quantum network node composed of a single Rb87 atom coupled to two crossed fiber resonators, one mediating the generation of a photonic qubit entangled with the atom, and the other collecting fluorescence photons for atomic state measurement. We achieve an entanglement generation efficiency of 44%, and we measure an atomic state in 7.5us with a fidelity of 98.5%. The implementation of such a node in a quantum network would be beneficial for quantum communication protocols that involve the distribution of entanglement between nodes as a resource.

Q 38.24 Wed 17:00 KG I Foyer

Active Polarization Modulation of Passive Entangled Photon Pair Sources — •Sabine Häussler[1], Philippe Ancsin[1], Meritxell Cabrejo-Ponce[1,2], Rodrigo Gómez[1,2], and Fabian Steinlechner[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Straße 7, 07745 Jena, Germany — [2]Friedrich Schiller University, Institute of Applied Photonics, Abbe Center of Photonics, Albert-Einstein-Str. 12, 07745 Jena, Germany

Entangled photon pair sources (EPS) are typically optimized to produce a single well-defined quantum state. While such passive sources are highly suitable for quantum key distribution (QKD), more advanced cryptographic protocols with multiple parties, such as quantum secret sharing (QSS), demand more flexible sources that incorporate active modulation. In our previous research, we have examined the feasibility for multi-partite QKD using an EPS with active state modulation. There, the EPS is based on a complete in-fiber Sagnac interferometer with a cascade of second-harmonic generation and downconversion in two nonlinear waveguides. This setup offers high brightness, phase stability, and high-speed active modulation. However, in this configuration, Raman noise in fibers represents an issue that limits performance. To overcome this restriction, the active modulation is moved outside the Sagnac loop to the pump preparation stage. This active system for polarization encoding is combined with a passive EPS, giving altogether a better performing system for flexible applications in QKD. The system was characterized regarding its applicability as a reconfigurable quantum network for QSS.

Q 38.25 Wed 17:00 KG I Foyer

Time-Bin QKD with Wavelength-Division Multiplexing — •Niklas Humberg, Alejandro Sánchez-Postigo, and Carsten Schuck — Departement for Quantum Technology, Münster, Germany

When doing Quantum Key Distribution, there are several different approaches to increase the secret key rate of a quantum channel. One possibility is Wavelength-Division Multiplexing (WDM), where photons of several different wavelengths are sent simultaneously in parallel over the same channel. These time-bin encoded qubits are generated by a narrow-band laser with adjustable wavelength in combination with electro-optic modulators for pulse generation. After transmission through a quantum channel with up to 90 km length, the qubits are demultiplexed and analyzed in the time domain using an 8-channel silicon nitride-on-insulator photonic integrated circuit. We use Mach-Zehnder interferometers with a 200 ps on-chip delay line to measure in complementary bases and enable a maximal key generation rate of up to 2.5 Gbit/s employing NbTiN superconducting nanowire single-photon detectors (SNSPDs) with high timing accuracy. We present simulation results, the QKD setup, and first measurements.

Q 38.26 Wed 17:00 KG I Foyer

Low Noise Quantum Frequency Conversion of SnV-Resonant Photons to the Telecom C-Band — •David Lindler, Tobias Bauer, Marlon Schäfer, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

Tin-Vacancy-Centers (SnV) in diamond represent a promising candidate for quantum nodes in quantum communication networks, that store, process and distribute quantum information [1,2]. To exchange the information between these nodes over long distances through optical fiber links, the spin state of the SnV-Center is transfered onto single photons. These photons are then converted into the low-loss telecom bands via quantum frequency down-conversion, to avoid the problem of high loss in fibers for SnV-resonant photons at 619 nm. Scaling this to large networks requires a shared frequency reference frame to ensure, e.g, the indistinguishability of two converted photons from different nodes, when performing a Bell state measurement.

We here present a two-stage low noise scheme for quantum frequency conversion of SnV-resonant photons to the telecom C-band based on difference frequency generation in PPLN waveguides. The two step process drastically reduces noise at the target wavelength compared to the single step process [3]. We will present the conversion efficiency, conversion-induced noise count rates, and initial results on the frequency stabilization of the mixing laser.

[1] J. Görlitz et al., npj Quant.Inf. 8, 45 (2022).
[2] R. Debroux et al., Phys. Rev. X 11, 041041 (2021).
[3] M. Schäfer et al., Adv Quantum Technol. 2300228 (2023).

Q 38.27 Wed 17:00 KG I Foyer

Polarization-Preserving Quantum Frequency Conversion of $^{40}Ca^+$-Resonant Photons to the Telecom C-Band — •Tobias Bauer, David Lindler, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

In quantum communication networks information is stored in internal states of quantum nodes, which can be realized e.g. in trapped ions like $^{40}Ca^+$ [1] or SnV color centers in diamond [2]. By transferring the states onto flying quantum bits, i.e. photons, it is possible to exchange information between these nodes over long distances via optical fiber links. Utilizing quantum frequency conversion to a common target wavelength enables the entanglement of dissimiliar quantum memories and drastically reduces fiber attenuation by choosing a target wavelength in a low loss telecom band.

We present a high-efficiency, rack-integrated quantum frequency converter for polarization-preserving conversion of $^{40}Ca^+$-resonant photons to the telecom C-band. This converter is highly suited for real-world applications in urban area fiber networks, e.g. photonic entanglement distribution [3] or creation of remote entanglement of atomic systems. We will also show first progress towards the entanglement of a $^{40}Ca^+$-ion with a SnV center by stabilizing the mixing lasers for

both conversion processes to a common frequency reference.
[1] C. Kurz et al., Phys. Rev. A. 93, 062348 (2016)
[2] J. Görlitz et al., npj Quant.Inf. 8, 45 (2022)
[3] E. Arenskötter, T. Bauer et al., npj Quantum Inf 9, 34 (2023)

Q 38.28 Wed 17:00 KG I Foyer

Coherent excitation of tin vacancy centres in diamond using a cross-polarization excitation scheme — •Dennis Herrmann, Robert Morsch, and Christoph Becher — Fachrichtung 7.2, Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken, Germany

In recent years the tin vacancy centre (SnV) in diamond has raised interest in the QIP community as it offers bright and pure single photon emission into lifetime limited optical transitions combined with long spin dephasing times on the order of $T_2^* \sim 5\mu s$ [1,2,3]. The coherent control of qubits and the generation of spin-photon entanglement typically requires resonantly driving optical transitions of the SnV centre. A spectral separation of excitation and emission wavelengths is highly desirable to discriminate the strong driving against single emitted photons. However, in the level scheme of the SnV centre we find that the large ground state splitting leads to a fast population decay from the upper to the lower orbital ground state making it necessary to excite and read out on the same optical transition. Here we deploy a homebuilt cross-polarisation confocal microscopy setup as demonstrated for semiconductor systems [4,5]. Offering polarisation extinction ratios of up to 10^7 it is enabling the strong polarisation selective suppression of laser light with respect to orthogonally polarised photons emitted on the same optical transition. Using short excitation pulses of below $250ps$ we furthermore demonstrate coherent Rabi-Oscillations.

1. New J. Phys. 22, 013048 (2020). 2. npj Quantum Inf 8, 45 (2022). 3. Phys. Rev. X 11, 041041 (2021). 4. Phys. Rev. X 11, 021007 (2021). 5. Rev. Sci. Instrum. 84, 073905 (2013).

Q 38.29 Wed 17:00 KG I Foyer

Indistinguishable single photons from negatively charged tin-vacancy centres in diamond — •R. Morsch[1], D. Herrmann[1], J. Goerlitz[1], B. Kambs[1], P. Fuchs[1], P.-O. Colard[2], M. Markham[2], and C. Becher[1] — [1]Fachrichtung 7.2, Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken, Germany — [2]Element Six Global Innovation Centre, Fermi Avenue, Harwell Oxford, Didcot, Oxfordshire, X11 0QR, UK

Within the field of quantum information processing (QIP) numerous schemes demand long-lived, stationary qubits, that can be controlled coherently and read out optically. Furthermore, a linear optics quantum computer inherently relies on the emission of single indistinguishable photons. The negatively charged tin-vacancy centre (SnV-) in diamond has made its mark as a promising candidate for these applications. Individually addressable spins with long coherence times as well as bright emission of single, close-to-transform limited photons render it a good light-matter interface. Moreover, recent studies point towards high achievable indistinguishabilities upon resonant excitation. Here we present our work on different excitation schemes for the generation of single indistinguishable photons emitted by SnV-centres: In off-resonant excitation we find the indistinguishability of the single photons to be limited due to the high excitation powers needed. We further evaluate different approaches for excitation within the SnV multi-level scheme and discuss their limitations. Eventually we report on the state of experiments on emission of indistinguishable single photons upon resonant excitation in a homebuilt cross-polarization setup.

Q 38.30 Wed 17:00 KG I Foyer

Highly-automated quantum frequency conversion device for single photons from SnV centers in diamond — •Marlon Schäfer, David Lindler, Tobias Bauer, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

Quantum frequency conversion of single photons to low-loss telecom bands is one of the key enabling technologies to distribute entanglement in fiber-linked quantum networks. However, in order to make this technology viable for real-world applications, quantum frequency converters must ensure robust 24/7 operation even outside of laboratory conditions and without human intervention.

Here, we investigate the employment of automation technology in quantum frequency converters aiming to increase robustness, stability and functionality. In particular automatic beam alignment and beam position stabilization are used to ensure long-time stable operation even under varying ambient conditions. We aim to automate a conversion process, where in two separate PPLN waveguides photons resonant with tin-vacancy (SnV) centers in diamond are first converted to an intermediate wavelength and then to the telecom C-band. Such a two-stage scheme was recently shown to successfully circumvent pump-induced noise for the conversion of single photons from silicon-vacancy centers to diamond [1].

[1] Schäfer, M. et al., Adv Quantum Technol. 2023, 2300228.

Q 38.31 Wed 17:00 KG I Foyer

A portable warm vapour quantum memory — •Martin Jutisz[1], Alexander Erl[2,3], Elisa Da Ros[1], Luisa Esguerra[3,2], Janik Wolters[3,2], Mustafa Gündoğan[1], and Markus Krutzik[1,4] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany — [3]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany — [4]Ferdinand-Braun-Institut (FBH), Berlin, Germany

Warm vapor quantum memories have seen significant progress in terms of efficiency and storage time in recent years. Their low complexity makes them a promising candidate for operation in non-lab environments including space-based applications. As a necessary element of quantum repeaters, memories operating in space could advance global quantum communication networks [1].

We will present the implementation and performance of a portable rack-mounted stand alone system, that includes also the laser system and control electronics. The optical memory is based on long-lived hyperfine ground states of Cesium which are connected to an excited state via the D_1 line at 895 nm in a lambda-configuration. The stability of the memory efficiency and fidelity is demonstrated at single photon level. Different methods to micro integrate this platform are also being investigated.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RP2090 & 50WM2347.

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)

Q 38.32 Wed 17:00 KG I Foyer

Processing of Tapered Fibres with Concave End Facets for Quantum Networks — •Lasse Jens Irrgang[1], Georgia Eirini Mandopoulou[1,3], Timo Eikelmann[1], Mara Brinkmann[1], Tuncay Ulas[1], Sunil Kumar Mahato[1,2], Donika Imeri[1,2], Rikhav Shah[1], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany — [3]Department of Physics, Harvard University, Cambridge, MA 02138, USA

A key aspect in the creation of quantum networks for quantum communication based on trapped ions or vacancy centres is the interface between photons travelling in fibres and the qubit. For an efficient connection, fibres need to be processed to fit the application. We present a set-up based on laser ablation which allows for precise machining of fibres and presents an alternative to the current technique of etching with hydrofluoric acid. Specifically, we produce concave end facets and tapered profiles with desired properties. The applications include low noise microcavities in QED-based interfaces to trapped ions or Rydberg atoms. Fibres exhibiting only the tapered profile can also be used for a connection to silicon vacancy centres in diamond.

Q 38.33 Wed 17:00 KG I Foyer

Robust Dynamical Decoupling Driven by Pulses with Field Inhomogeneities in Pr:YSO — •Niklas Stewen, Markus Stabel, and Thomas Halfmann — Technische Univeristät Darmstadt, Germany

We present a demonstration experiment in which we compare the robustness of state-of-the-art composite pulse (CP) sequences for dynamical decoupling with regard to typically unavoidable inhomogeneities in the driving radiofrequency (RF) pulses. To systematically vary and characterize the field inhomogeneity, we modify the winding number of our driving RF coils, and, using an orthogonal addressing of the crystal, perform a spatially resolved measurement of the Rabi frequency distribution in 3D. We quantify the performance of CP sequences at different inhomogeneities by measuring the coherence time of EIT light storage in a Pr:YSO crystal. We find that already for rather homogeneous driving fields, CP sequences and in particular the universal robust (UR) family of sequences provide a large improvement compared to the standard CPMG sequence. This advantage further increases with the field inhomogeneity.

Q 38.34 Wed 17:00 KG I Foyer

Towards Photonically Connected Quantum Nuclear Microprocessors — •Donika Imeri[1,2], Timo Eikelmann[1], Mara Brinkmann[1], Lennart Manthey[1], Rikhav Shah[1], Lasse Jens Irrgang[1], Konstantin Beck[1], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Silicon-vacancy (SiV) color centers in diamond are promising candidates for enhancing quantum communication systems. SiVs exhibit advantageous characteristics as solid-state emitters with an effective optical interface and protective inversion symmetry. This setup enhances the entanglement generation between spin qubits and photonic qubits, which is a crucial step toward building scalable quantum communication networks. Key challenges in achieving coherent interactions between nuclear spins and SiV are ultra-low temperatures and strong currents that generate radio-frequency fields. Here, we present a platform integrating nuclear magnetic resonance coils with nanophotonic structures designed to operate at millikelvin temperatures, thus paving the way for advancements in quantum networks using SiV-based systems.

Q 38.35 Wed 17:00 KG I Foyer

A Protocol for Multiplexed Entanglement Generation with Distinguishable Telecom Emitters — •Fabian Salamon[1,2], Olivier Kuijpers[1,2], Adrian Holzäpfel[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Technische Universität München, TUM School of Natural Sciences, James-Franck-Straße 1, 85748 Garching, Germany

Second-long spin coherence times and emission in the minimal-loss telecommunication window make erbium dopants in solid-state host crystals a particularly attractive candidate for future quantum network applications [1].

Spectral diffusion has so far prevented the generation of entanglement between these erbium emitters, since most entanglement protocols require the emission of indistinguishable photons. Here, we present a protocol that bypasses this constraint: Upon reflection on a strongly coupled atom-cavity system, a high-fidelity controlled-Z gate can be applied to a photon [2]. Since the bandwidth of this gate is larger than the spectral diffusion, entanglement can be generated between two distinguishable erbium emitters.

The envisioned hybrid platform combines a large-scale multiplexing capability with insensitivity to spectral diffusion. This could enable entanglement generation over hundred kilometres of optical fiber at unprecedented rates.

[1] A. Reiserer, Rev. Mod. Phys. 94, 041003 (2022). [2] A. Reiserer, N. Kalb, G. Rempe & S. Ritter, Nature 508(7495), 237-240 (2014).

Q 38.36 Wed 17:00 KG I Foyer

Exploring Germanium-Vacancy Centers in Diamond Cavities for a Quantum Repeater Module — •Prithvi Gundlapalli, Katharina Senkalla, Lev Kazak, Philipp Vetter, Stefan Dietel, and Fedor Jelezko — Universität Ulm

Diamond photonic cavities present a compelling architectural framework for effectively addressing individual spins associated with diamond color centers, thereby enabling the scalability of diverse quantum applications in sensing, computing, and networking. An essential prerequisite for quantum networks involves entangling color centers separated over considerable distances, necessitating the employment of quantum repeaters due to the unreliable transmission of flying qubits over such distances. Notably, group IV defects like Ge, Sn, and Pb vacancy centers within diamond exhibit promising attributes such as efficient light-matter interfaces as well as long coherence times, which are conducive to serving as candidates for quantum repeaters. We present our progress on the development of diamond photonic cavities integrated with Germanium vacancy centers (GeV) as well as simulation results that allows for efficiently building quantum registers. These will ultimately be used to develop a quantum repeater module.

Q 38.37 Wed 17:00 KG I Foyer

Titel — •Leon Messner[1], Helen Chrzanowski[1], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Berlin, Germany — [2]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany

We present first results and future prospects for a photon-pair source based on spontaneous parametric down-conversion (SPDC) in a periodically poled monolithic KTP crystal cavity[1]. By proper engineering of the cavity parameters and phase-matching, it is possible to tune the source for interfacing with atomic systems and particularly with quantum memories.

By putting the cavity end mirrors directly on the non-linear crystal we have build a photon-pair source that is set to a dedicated signal and idler wavelength of 895 nm with a bandwidth of 250 MHz and a cavity finesse of 90 while retaining a tuneability of 20 GHz. The source emits photon pairs at a rate of 40 kcts/s with an heralding efficiency of 38%, limited by the current choice of collimation optics.

We plan on interfacing our source with a warm vapor EIT quantum memory[2] to explore synchronizing the probabilistic photon source to a fixed clock rate. In addition to investigating typical parameters of quantum memories such as efficiency and maximum storage time, we will measure the attainable two-photon interference between a photon retrieved from the memory and one directly from the source.

[1] Mottola, R. et al., Optics Express **28**, 3159-3170 (2020)
[2] Buser, G. et al., PRX Quantum **3**, 020349 (2022)

Q 38.38 Wed 17:00 KG I Foyer

Towards a fully integrated SU(1,1) interferometer in a periodically poled Ti:LiNbO3 waveguide — •Jonas Babai-Hemati, Kai Hong Luo, Raimund Ricken, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

There is an increasing interest in quantum interferometers in metrology as they can outperform their classical counterparts. The most prominent quantum interferometer is a SU(1,1) interferometer, which has a Mach-Zehnder configuration with the conventional passive beamsplitters replaced by nonlinear parametric sections. We designed and fabricated a fully integrated SU(1,1) interferometer on a single LiNbO3 chip. Optical waves are guided in Ti-indiffused waveguides. The parametric sections comprise of periodically poled sections for type II phase-matched paramentric down-conversion (PDC) in the telecom range. A series of electrooptic polarization converters (PC) and two electrooptic phase-shifters allows the manipulation of the phase- and/or polarization state in between the nonlinear sections. The exact phase-matching of PDC and PC can be adjusted via temperature tuning in three separate sections of the chip. We report on the design and the fabrication of the integrated chip as well as on the classical characterization of the individual components forming the circuit. Quantum measurements to study the interferometer performance in phase-sensing as well as the use of such a device for tailored quantum state preparations are presently in a planning stage.

Q 38.39 Wed 17:00 KG I Foyer

Optical Coherence Tomography with Undetected Photons Based on an Integrated PDC Source — •Franz Roeder, René Pollmann, Michael Stefszky, Victor Quiring, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn

Interferometry allows us to perform phase measurements with high precision to gain information about a system of interest, e.g., in a classical Mach-Zehnder interferometer. Replacing passive beam splitters of a Mach-Zehnder interferometer with active elements, such as parametric down-conversion (PDC) sources yields a so-called SU(1,1) interferometer. By operating the SU(1,1) interferometer with two non-degenerate wavelengths, for instance in the mid-IR and visible, it becomes possible to retrieve the phase properties of an object interacting with the mid-IR light by measuring only the visible light.

Here, we utilize broadband non-degenerate type-II PDC in dispersion engineered periodically poled lithium niobate waveguides as active elements of such an interferometer, which brings the benefit of significantly reduced energy consumption for a given signal-to-noise ratio, and demonstrate optical coherence tomography (OCT) with undetected photons. Furthermore, we investigate the conditions for an optimized signal-to-noise ratio by compensating for losses in the interferometer in a differential pumping scheme.

Q 38.40 Wed 17:00 KG I Foyer

Criticality-Enhanced Precision in Phase Thermometry — •Mei Yu, H. Chau Nguyen, and Stefan Nimmrichter — University of Siegen, Siegen, Germany

Temperature estimation of interacting quantum many-body systems is both a challenging task and topic of interest in quantum metrology, given that critical behavior at phase transitions can boost the metrological sensitivity. Here we study non-invasive quantum thermometry of a finite, two-dimensional Ising spin lattice based on measuring the non-Markovian dephasing dynamics of a spin probe coupled to the lattice. We demonstrate a strong critical enhancement of the achievable precision in terms of the quantum Fisher information, which depends on the coupling range and the interrogation time. Our numerical simulations are compared to instructive analytic results for the critical scaling of the sensitivity in the Curie-Weiss model of a fully connected lattice and to the mean-field description in the thermodynamic limit, both of which fail to describe the critical spin fluctuations on the lattice the spin probe is sensitive to. Phase metrology could thus help to investigate the critical behaviour of finite many-body systems beyond the validity of mean-field models.

Q 38.41 Wed 17:00 KG I Foyer

Hyperpolarization of nuclear spins to mitigate diffusion broadening in liquid nanoscale NMR with NV centers — •Tobias Spohn[1], Nicolas Staudenmaier[1], Gerhard Wolff[1], Anjusha Vijayakumar-Sreeja[1], Genko Genov[1], Philipp Vetter[1], Raúl Gonzalez[1], Jochen Scharpf[2], Thomas Unden[2], Christoph Findler[1,3], Johannes Lang[3], Jens Fuhrmann[1], Philipp Neumann[2], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [2]NVision Imaging Technologies GmbH, Wolfgang-Paul-Straße 2, 89081 Ulm, Germany — [3]Diatope GmbH, Buchenweg 23, 88444 Ummendorf, Germany

In liquid nanoscale NMR the amplitude and phase of the acquired signal changes due to molecular diffusion of the nuclear spins. This causes spectral broadening of the acquired signal and therefore impedes resolution of chemical shifts and J-coupling.

Here we present a technique to mitigate diffusion broadening in nanoscale NMR experiments by the use of hyperpolarization of nuclear spins. We explore two potential techniques: The para-hydrogen induced polarization (PHIP) technique and the use of the stabilized radical TEMPO to induce polarization on hydrogen nuclear spins. The NMR signal is detected by a high density, nanometer thick, shallow NV center ensemble layer and read out with a widefield microscope setup. The directional polarization of nuclear spins reduces spectral broadening as diffusion will no longer play a role anymore due to the average signal remaining the same.

Q 38.42 Wed 17:00 KG I Foyer

Excited state lifetime of NV-centers for magnetometry — •Ludwig Horsthemke[1], Jens Pogorzelski[1], Lutz Langguth[3], Robert Staacke[3], Markus Gregor[2], and Peter Glösekötter[1] — [1]Department of Electrical Engineering and Computer Science, FH Münster University of Applied Sciences, Stegerwaldstraße 39, Steinfurt, Germany — [2]Department of Engineering Physics, FH Münster University of Applied Sciences, Stegerwaldstraße 39, Steinfurt, Germany — [3]Quantum Technologies GmbH, Alte Messe 6, Leipzig, Germany

Magnetic field sensing using nitrogen vacancy centers has attracted a lot of attention in the recent past. Approaches using microwave (MW) excitation realize high sensitivities and spatial resolutions. They are however limited in their application due to the necessity of MW delivery. In contrast all-optical approaches simplify the sensor design in a step towards industry application. They can be implemented using fiber optics to construct a non-magnetic, high insulation resistance probe and can thereby be applied in harsh environments. These designs still encounter challenges such as movement in the optical fiber or laser intensity noise, compromising the fluorescence signal. In this study we utilize the fluorescence lifetime as a non-intensity quantity for magnetic field sensing. The lifetimes show a good correlation with the intensity by a reduction with a contrast of 8.3% upon application of magnetic fields. The integration of this approach holds promise for advancing magnetic field sensing capabilities, particularly in environments where conventional methods face limitations.

Q 38.43 Wed 17:00 KG I Foyer

Progress towards single photon EIT light storage at ZEFOZ conditions in Pr:YSO — •Marcel Hain, Tom Güntzel, and Thomas Halfmann — Nonlinear Optics & Quantum Optics (NLQ), Institute of Applied Physics, TU Darmstadt, Germany

Long storage time, large storage efficiency, and large signal-to-noise ratio (SNR) are crucial properties of optical quantum memories. We present single- and few-photon storage based on electromagnetically induced transparency (EIT) in praseodymium-doped yttrium orthosilicate (Pr:YSO). By employing zero first-order Zeeman shifts (ZEFOZ) and dynamical decoupling based on robust composite pulse sequences we reach storage times on the timescale of seconds. We apply a specifically designed spectral filter implemented in an additional Pr:YSO crystal to separate the weak signal pulse from the strong optical control field. Previously, we reached a SNR=1 for stored weak coherent pulses with 11 photons at a storage time beyond one second [1].

We present now recent progress towards single photon storage by EIT in Pr:YSO. We simultaneously prepare two ensembles to increase the optical depth, thereby enabling higher efficiency. Furthermore, we optimized the optical setup, among other measures using now an ECDL-based laser system (replacing the previously applied OPO system), which helps to improve the spectral filter discrimination by almost two orders of magnitude. This pushes the SNR towards the required regime for single photon storage.

[1] M. Hain, M. Stabel, and T. Halfmann. New J. Phys. **24**, 023012 (2022)

Q 38.44 Wed 17:00 KG I Foyer

Optimal valley control in 2D materials with subcycle laser pulses — •Arkajyoti Maity, Ulf Saalmann, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38,01187 Dresden

Information processing, using the valley degrees of freedom in inversion symmetric 2D materials is possible with the help of specifically designed ultrafast laser pulses. In our work, we theoretically show how linearly polarized terahertz subcycle laser pulses allow us to obtain a saturation of valley polarization (VP) in monolayer graphene . We further exploit the matching of the Thz drive time scales with dephasing rates in the material to get amplitude-controlled valley-polarized responses, namely residual photocurrents. We also present some results on pulse-shaping, both in spectral-phase and polarization domain, for efficient VP.

Q 38.45 Wed 17:00 KG I Foyer

Engeneering of tin vacancies in diamond by lattice charging — •Vladislav Bushmakin[1,2], Oliver von Berg[1], Santo Santonocito[1], Sreehari Jayaram[1,2], Rainer Stöhr[1], Andrej Denisenko[1,2], and Jörg Wrachtrup[1,2] — [1]Universität Stuttgart, 3. Physikalisches Institut, Allmandring, 13, 70569, Stuttgart, Germany — [2]Max-Plank-Institut für Festkörperforschung Heisenbergstraße 1, 70569 Stuttgart, Germany

Recent advances in integrating spin-bearing solid-state defects in optical cavities for efficient spin-photon entanglement are mostly associated with silicon vacancy in diamond. Meanwhile, the implantation of diamond with heavier group IV ions promises similar performance but at elevated temperatures above 1 K, which contrasts with the stringent requirement of approximately 100 mK for the coherent manipulation of the SiV electron spin. However, the generation of defects involving heavier atoms, such as tin, is accompanied by a high density of defects induced by ion implantation. Here we present a method of reduction of the implantation-induced density of defects by implanting through the Boron-doped charged lattice with a subsequent etching of the damaged layer. The given method is an extension of the conventional implantation technique and hence significantly less experimentally demanding than techniques relying on CVD overgrowth or HPHT annealing. Additionally, it provides better accuracy of implantation and allows for the efficient generation of tin vacancies with a narrow inhomogeneous zero-phonon line distribution.

Q 38.46 Wed 17:00 KG I Foyer

Spatial search via quantum walk on lattices with long-range hopping — •Moritz Linnebacher, Emma King, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Spatial search forms the basis of many noteworthy classical and quantum algorithms. In some settings, quantum spatial search achieves runtimes of $\mathcal{O}(\sqrt{N})$ compared to its classical counterpart with runtimes of $\mathcal{O}(N)$, where N is the size of the search space. In our work we implement spatial search via continuous-time quantum walk on lattices comprising N sites with long-range hopping. The hopping strength decays as $1/\ell^\alpha$ with inter-site distance ℓ and the exponent $\alpha \in [0, \infty)$. We focus on one- and two-dimensional lattices with $d = 1, 2$, where a rigorous numeric treatment shows that the search succeeds with high probability in $\mathcal{O}(\sqrt{N})$ runtime for $\alpha \leq d$, even in $d = 1$ spatial dimension. For lattices with nearest-neighbour interactions, corresponding to $\alpha \to \infty$, the quadratic speedup over classical spatial search is lost. This highlights the importance of considering long-range interactions for search in low-dimensional lattices.

Q 38.47 Wed 17:00 KG I Foyer

quantum optimal control for GHZ-class states — •yitian wang and christiane koch — Freie Universität Berlin, Berlin, Germany

We present an optimization functional that targets the entire class of GHZ states. Optimization has been carried out in trapped Rydberg atoms with varying number of qubits. Compared with state-state overlap based optimization functional, our functional can significantly reduce the resource required to produce a random GHZ state, thus facilitate protocols based on GHZ-class states.

Q 38.48 Wed 17:00 KG I Foyer

Correlations in two-photon-excited ion chains — •Zyad Shehata[1,3], Stefan Richter[1,2], Benjamin Zenz[4], Maurizio Verde[4], Ansgar Schaefer[4], Ferdinand Schmidt-Kaler[4], and Joachim von Zanthier[1,3] — [1]AG Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany — [2]Photonscore GmbH, 39118 Magdeburg, Germany — [3]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander-Universität Erlangen-Nürnberg, Paul-Gordan-Straße 6, 91052 Erlangen, Germany — [4]QUANTUM, Institut für Physik, Johannes Gutenberg Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

In this work, small crystals of trapped Ca-ions are studied using background-free coherent scattering and two-photon excitation via the D5/2 metastable state. The narrow quadrupole transitions allows for spin selective excitation and thus for far field imaging of the spin state of the crystals using G(1) function. The visibility of the interference pattern depends on the power and the detuning of the two lasers at 729 nm and 854 nm employed in the two-photon excitation as well as on the strength and orientation of the magnetic field that splits the ground state spin states. To calculate G(1), a full interaction Hamiltonian of the system including the two laser beams and all transitions involved is solved numerically for any number of ions, and experimental spatial frequencies of ion crystals are reconstructed for low exposure times (250 ms - up to 1 s) and detected by an ultra-fast picosecond-time-resolution camera.

Q 39: Poster V

Time: Wednesday 17:00–19:00 Location: Aula Foyer

Q 39.1 Wed 17:00 Aula Foyer

Simulations of Anti-Resonant Waveguiding In Hollow Core Fibers — •Lucas Kirchbach, Andreas Stute, Manfred Kottcke, and Bernd Braun — Technische Hochschule Nürnberg Georg Simon Ohm

Standard optical fibers guide light through total internal reflection in high refractive index material such as glass or polymers surrounded by low index material. Guiding light in optically dense matter however has some major disadvantages: Absorption, dispersion and Rayleigh-scattering place a lower bound to attenuation. In this work, a photonic crystal structure based on interference was studied, where light is guided in air surrounded by optical dense media. An attenuation of sub 0.1 db/km has been simulated numerically by optimizing the geometry of the fiber cross section.

Ultra low-loss optical waveguides open up many possibilities for the design of laser resonators on the one hand and optical interfaces between atoms, quantum dots, NV-centers and light sources and detectors on the other hand. Those technologies require highly efficient light-coupling that can be directed at will.

Q 39.2 Wed 17:00 Aula Foyer

Application of an integrated optical Mach-Zehnder interferometer for chemical sensing — •Johannes Schnegas[1], Karo Becker[2], Alexander Szameit[2], and Udo Kragl[1] — [1]Universität Rostock, Institut für Chemie, Rostock, Deutschland — [2]Universität Rostock, Institut für Physik, Rostock, Deutschland

Integrated optics offers a great advantage in the field of analytical chemistry to produce miniaturised optical sensors for the selective detection of analytes. An interesting sensor application are integrated optical interferometers, such as the Mach-Zehnder interferometer. This approach has been tested successfully for the concentration measurement and selective detection of proteins, gases, and DNA fragments. Real-time detection of small changes in the surrounding refractive index is possible. Most publications describe integrated optical MZI fabricated by photolithography, where the optical waveguides are made of silicon nitride or polymers. These waveguides were placed directly on a support such as silicon. In this work, an integrated optical MZI made of femtosecond laser-written near-surface waveguides is tested as a chemical sensor. The concept of near-surface waveguides as chemical sensor such as oils has already been tested. In this study, integrated optical Mach-Zehnder interferometers were tested for their ability to detect different types of analytes, with the intention of using the integrated optical interferometer for concentration measurement.

Q 39.3 Wed 17:00 Aula Foyer

Ultra high throughput single photon detection — •Sebastian Karl[1], Verena Leopold[1,2], Stefan Richter[1,2], Yury Prokazov[2], Evgeny Turbin[2], Gennady Sintotskiy[2], Dimitry Orl[3], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, FAU Erlangen Nürnberg, Germany — [2]Photonscore GmbH, Magdeburg, Germany — [3]Photonis Netherlands BV, Roden, Netherlands

Although recently there has been a tremendous push towards detectors with near unity quantum efficiencies and high timing resolution [1], the dead time of most single photon detection systems remains on the order of 30 ns. Avoiding unwanted pile-up effects this dead time limits the photon detection rate to less than 15 MHz.

We present tests of a novel single photon counting system able to detect single photons at rates exceeding 100 MHz on one single point detector. Photon detection is achieved using a multichannel-plate and a 8 mm diameter Photonis Hi-QE photocathode, reaching quantum efficiencies above 30%. A custom time to digital converter (TDC), Photonscore LINTag, is used to digitise the photon arrival times. It allows the data transfer of event rates exceeding 400 MHz per TDC via standard 10G ethernet fibre cables. At sustained photon detection rates of 100 MHz we measure a jitter of $<$ 70 ps FWHM. Using a spinning disk optical chopper we show reliable single photon detection and timing at instantaneous rates exceeding 500 MHz.

[1] I. E. Zadeh et al., Appl. Phys Lett. 188, 190502 (2021)

Q 39.4 Wed 17:00 Aula Foyer

Towards spatial correlations of A-type stars in the blue — •Verena Leopold[1,2], Sebastian Karl[1], Jean-Pierre Rivet[3], Stefan Richter[1,2], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, FAU Erlangen, Germany — [2]Photonscore GmbH, Magdeburg, Germany — [3]Observatoire de la Côte d'Azur, Nice, France

Intensity interferometry is a reemerging astronomical imaging technique, benefiting immensely from the recent improvements in (single) photon detection instrumentation. Our goal is to perform spatial correlations of A-type stars in the blue using ultra high-rate single photon detectors. We present a setup for the C2PU telescope at the Calern observatory, Nice, France, featuring hybrid single photon counting detectors (HPDs) with which we measured successfully temporal correlations of three different stars - Vega, Altair and Deneb. In all cases the observed coherence time fits well to both the pre-calculated expectations as well as the value measured in preceding laboratory tests. The best signal to noise ratio (SNR) with a value of 10.72 is obtained for Vega for an observation time of 12.1 h. The setup showed remarkable stability and very efficient coupling of the starlight to the photo detectors, owed mainly to the large active area of the HPDs. Utilizing a new class of large area single photon detectors based on multichannel plate amplification, we estimate that high resolution spatial intensity interferometry experiments are within reach at 1 m diameter class telescopes within one night of observation time for bright stars.

Q 39.5 Wed 17:00 Aula Foyer

Effects of Pyroelectricity on the Fabrication Yield of Integrated Superconducting Detectors on Lithium Niobate — •Johanna Biendl[1], Felix Dreher[1], Maximilian Protte[1], Jan Philipp Höpker[1], Varun B. Verma[2], and Tim J. Bartley[1] — [1]Institute for Photonic Quantum Systems, Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn — [2]National Institute of Standards and Technology, CO 80305 Boulder, USA

Reconfigurable photonic quantum systems require a combination of integrated photon sources, modulators and detectors. The best candidates for the realization of on-chip detection are superconducting detectors due to their high efficiency, low dark count rate and good timing accuracy. For the integration of photonic devices, z-cut lithium niobate has proven as an excellent material because of its strong second-order nonlinearity and electro-optic effect. However, the pyroelectric effect causes irreversible damage to integrated superconducting detectors when cooling them down to cryogenic temperatures due to sudden discharges of fields generated by pyroelectric charges. This limits detector fabrication yield to less than 5%. To overcome this limitation we investigate different methods including coating materials, detector dimensions and shorting schemes to compensate the generated charges without constraining the functionality of integrated devices and optical waveguides.

Q 39.6 Wed 17:00 Aula Foyer

Spectral purification of spontaneous parametric down-conversion photons via spatial filtering — •Michael Schlosser[1], Ria G. Krämer[2], Julian Münzberg[1], Daniel Richter[2], Stefan Nolte[2,3], Gregor Weihs[1], and Robert Keil[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, Albert-Einstein-Str. 15, D-07745 Jena, Germany — [3]Fraunhofer Institute for Applied optics and Precision Engineering IOF, Center of Excellence in Photonics, Albert-Einstein-Str. 7, D-07745 Jena, Germany

The application of photonic quantum technologies on a larger scale typically requires photons from independent sources to be indistinguishable. We report on a spontaneous parametric down-conversion (SPDC) source, which can simultaneously emit two photon pairs with a wavelength of 795nm. The joint spectral intensity of the pairs is measured via time-of-flight spectroscopy utilising femtosecond-laser inscribed fiber Bragg gratings as dispersive elements. The spectral purity extracted from this substantially exceeds the measured Hong-Ou-Mandel (HOM) interference visibility of 39(2)%, which suggests the presence of spatial-spectral correlations in the pump. To counter these, spatial filtering is investigated. A short single-mode fiber inserted into the pump indeed removes these correlations, increasing the HOM visibility to 79(15)%. Alternatively, inserting a 15μm-diameter pinhole in the Fourier plane of a telescope increases the indistinguishability to 48(2)%, while providing a steady power transmission.

Q 39.7 Wed 17:00 Aula Foyer

Enhancing atom-photon interaction with integrated nanophotonic resonators — •Xiaoyu Cheng[1] and Shnirman Benyamin[1,2] — [1]5. Physikalisches Institut, Universität Stuttgart — [2]Institut für Mikroelektronik Stuttgart (IMS-Chips)

We study hybrid devices consisting of thermal atomic vapor and nanophotonic structures for manipulating the interaction between atoms and photons.

We exploit cooperative effects to develop a compact, on-demand and highly efficient single-photon-source using the Rydberg blockade effect. In order to excite Rb atoms to the Rydberg states efficiently, the corresponding light field is locally enhanced by ultralow-loss microring resonators. Due to the large spatial extent of Rydberg atoms, we carefully design the ring resonators to realize sufficient interactions between Rydberg atoms and the evanescent field from the resonator. In order to create individual photons deterministically, we use the Four-Wave-Mixing (FWM) process in the Rydberg blockade regime inside a thermal vapor cell to develop a single-photon-source at room temperature.

To realize this goal, it is necessary to study Rydberg excitation in photonic integrated vapor cells. We excite and detect Rydberg excited Rb atoms with tapered, freestanding waveguides. Tapered narrow waveguides push out evanescent field that enables the excitation of Rydberg atoms. A specially designed, electric circuit patterned vapour cell and a transimpedance amplifier enables electric read out of single Rydberg excitation.

Q 39.8 Wed 17:00 Aula Foyer

Fabrication of polymer multimode-waveguides with maskless lithography for quantum sensing applications. — •Lena Middel, Tjorven Annika Husmann, Sreelakshmi Sathyan Kizhekayil, Jonas Homrighausen, and Markus Gregor — Department of Engineering Physics, University of Applied Sciences, Muenster

In the world of integrated quantum optics, multimode waveguides usually represent a niche, as singlemode waveguides enable on-chip processing of light. As the production of single mode waveguides is challenging in amounts of time, equipment and cost, our approach is to use multimode waveguides on applications that do not nessecarily require single mode waveguides. One such applications is quantum sensing using solid-state defects, such as the NV-center in diamond, which can be embedded in the waveguide to read out the spin dependent fluorescence [1]. Consequently, the aim of our work is the fabrication of dielectric ridge waveguides for structuring of SU-8. This epoxy-based negative photoresist is an excellent material with high and broadband optical transmission, high aspect ratio and good mechanical, thermal and chemical stability. For prototyping, we use a maskless lithography system, that is equipped with a digital micromirror device to project the image, leaving room for adjustment of exposed structures. This work paves the way for a more efficient and scalable production of waveguides for quantum sensing applications without the need for highly sophisticated equipment.

[1] P. P. Schrinner et al., (2020). Nano Letters, 20(11), 8170-8177.

Q 39.9 Wed 17:00 Aula Foyer

Higher Order Mode Supercontinuum Generation Through Nano-Printed Meta-Fiber — •Shahrzad Hosseinabadi, Mohammadhossein Khosravi, Matthias Zeisberger, Torsten Wieduwilt, and Markus Schmidt — Leibniz IPHT, Jena, Germany

Optical fibers, with their unique light guiding properties, have transformed modern society. Besides the common fundamental mode, fibers also support higher-order modes (HOMs), gaining attention for different applications. In nonlinear frequency conversion research, HOMs play a crucial role, offering access to unique dispersion landscapes. This enables applications such as broadband supercontinuum generation and exploration of novel nonlinear effects. However, efficiently exciting or converting HOMs poses a challenge due to the need for precise matching of modal properties, especially in nonlinear photonics. Current approaches, like spatial light modulators and waveplates, have limitations such as being costly, poorly integrated, and require extensive computer control and additional alignment. A promising solution involves dielectric nanostructures, specifically holograms and metasurfaces, offering unprecedented beam shaping capabilities with minimal losses. These approaches, based on well-designed flat elements, successfully modify intensity, phase distributions, and polarization, opening up possibilities for various applications. Our study focuses on investigating the potential of efficiently HOMs in nonlinear optical fibers. By leveraging technology of diffractive lenses, we aim to enhance the performance of HOMs, by proposing a highly integrated device for nonlinear photonics applications.

Q 39.10 Wed 17:00 Aula Foyer

Temperature Adaptable Supercontinuum Generation in Liquid-filled Fibers by Using Particle Swarm Optimization — •Johannes Hofmann, Ramona Scheibinger, and Markus A. Schmidt — Leibniz-Institute of Photonic Technology, Jena, Germany

Light sources in the IR regime with high spectral density and coherence are of great interest for e.g. spectroscopic approaches in life and environmental science. Supercontinuum (SC) generation due to nonlinear broadening of laser pulses in optical fibers with suitable dispersion profiles can meet the requirement of application specific spectral properties. Liquid-filled fibers offer the opportunity to modify the output spectra by temperature changes due to their large thermo-optic coefficient. Higher-order modes excited in CS2-filled step index fibers exhibit two zero-dispersion wavelengths (ZDW) which strongly shift with temperature. Pumping within the anomalous dispersion regime, the soliton dynamics can be modified and dispersive waves shift. In contrast to other methods of dispersion variation, such as varying the fiber geometry, controlling the temperature is not static, but highly variable. In addition, using a suitable optimization algorithm, such as Particle Swarm Optimization (PSO) the spectral output features can

be tuned to desired SC properties, e.g., maximizing the spectral intensity at one or more targeted wavelengths. Here, we investigate and shape the spectral evolution along a liquid-core fiber by applying a PSO to numerical SC generation simulations. Additionally, we present a automated experimental concept to achieve thermodynamic control of the fiber, leading to an adaptable output spectrum.

Q 39.11 Wed 17:00 Aula Foyer

Higher Order Mode Supercontinuum Generation Through Nano-Printed Meta-Fiber — •Shahrzad Hosseinabadi, Mohammadhossein Khosravi, Matthias Zeisberger, Torsten Wieduwilt, and Markus Schmidt — Leibniz Institute of Photonic Technology, Jena, Germany

Optical fibers, with their unique light guiding properties, have transformed modern society. Besides the common fundamental mode, fibers also support higher-order modes (HOMs), gaining attention for different applications. In nonlinear frequency conversion research, HOMs play a crucial role, offering access to unique dispersion landscapes. This enables applications such as broadband supercontinuum generation and exploration of novel nonlinear effects. However, efficiently exciting or converting HOMs poses a challenge due to the need for precise matching of modal properties, especially in nonlinear photonics. Current approaches, like spatial light modulators and waveplates, have limitations such as being costly, poorly integrated, and require extensive computer control and additional alignment. We explore the use of dielectric nanostructures specifically holograms and metasurfaces for advanced beam shaping with minimal losses. Our study specifically investigates the efficient utilization of HOMs in nonlinear optical fibers. Leveraging diffractive lenses technology, we aim to enhance HOMs' performance, proposing a compact integrated device for nonlinear photonics applications.

Q 39.12 Wed 17:00 Aula Foyer

TOWARDS CRYOGENICALLY COMPATIBLE MICROPHOTONIC QUANTUM INTERFACES — •Tuncay Ulas[1,2,3], Lasse Irrgang[1,2,3], and Ralf Riedinger[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Deutschland — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany — [3]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Deutschland

Quantum technologies are increasingly capturing the interest of researchers. These technologies rely on quantum physical operations applied to qubits. In our research group, we develop interfaces between cryogenic ion traps and optical fibers. Specifically, we are working on a cryogenic test station to assess the compatibility of the interface architectures.

Q 39.13 Wed 17:00 Aula Foyer

Sub-20ps-Jitter synchronisation of remote Time-to-Digital-Converters (TDC) — •Stefan Richter[1,2], Verena Leopold[1,2], Sebastian karl[1], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, FAU Erlangen Nürnberg, Germany — [2]Photonscore GmbH, Brenneckestr. 20, 39118 Magdeburg

With the emergence of various scientific applications of single-photon counting, such as intensity interferometry or quantum key distribution, measuring photons with high temporal precision at spatially distributed locations has become essential. To achieve this goal, signal capture must be executed using distributed time-to-digital converters (TDCs) that are synchronized to share a common time base with a constant offset to the TAI time. Ideally, the jitter of the synchronization should be on the order of the TDC jitter or lower. In our presentation, we demonstrate test measurements using a White Rabbit LEN system that employs PTP over standard telecommunication fibers along with self-developed TDCs. These tests show a synchronization RMS jitter of less than 20 ps for a link length of 50m. Although this value is larger than the jitter of the TDCs themselves, it does not exacerbate the overall jitter of the single photon detection system, as the MCP-based detectors have an RMS jitter of around 30 ps. Additionally, we have recorded temporal correlation measurements of single photons using White Rabbit synchronized TDCs, proving the high accuracy and precision of this approach for intensity interferometry use cases.

Q 39.14 Wed 17:00 Aula Foyer

Sensitivity optimization of diamond infrared-absorption based magnetometry — •Anil Palaci[1], Julian M. Bopp[1,2], Jonas Wollenberg[1], Felipe Perona[2], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

Negatively charged nitrogen vacancy (NV) color centers in diamond serve as excellent sensors for magnetic fields, electric fields, and temperature. By utilizing their spin-state dependent photoluminescence or absorption, NV centers enable the precise measurement of various physical and biological signatures under ambient conditions.

In this work, we exploit the NV center's infrared (IR) ${}^1E \leftrightarrow {}^1A_1$ transition for absorption-based magnetometry. Using a 1042 nm laser to probe the IR transition allows for magnetic field-dependent absorption. The high saturation intensity of the IR transition enables the use of high-intensity probe light, improving sensitivity limited by shot noise. However, due to the IR transition's low absorption cross-section, the implementation of a lock-in amplifier becomes necessary. To further enhance sensitivity, we optimize experimental parameters and settings of the lock-in amplifier. With the achieved sensitivity improvement, integration into highly sensitive compact systems becomes feasible without bulky optical setups.

Q 39.15 Wed 17:00 Aula Foyer

Microcontroller-optimized measurement electronics for NV-centers — •Dennis Stiegekötter[1], Jens Pogorzelski[1], Ludwig Horsthemke[1], Markus Gregor[2], and Peter Glösekötter[1] — [1]Department of Electrical Engineering and Computer Science, FH Münster University of Applied Sciences, Stegerwaldstraße 39, 48565 Steinfurt, Germany — [2]Department of Engineering Physics, FH Münster University of Applied Sciences, Stegerwaldstraße 39, 48565 Steinfurt, Germany

The integration and miniaturization of magnetic sensors based on diamonds with nitrogen vacancy centers is largely focused on the sensor tip. This means that the underlying electronics for excitation and readout of the spin states still offers great potential for further innovations. In this work the electronics adjust the power of the microwave. This makes it possible to tune the Rabi oscillation so that the time for a pi pulse is adapted to the microcontroller's limited temporal pulse resolution of Tp,min = 53.3 ns. This allows coherent control to be achieved even with a simple microcontroller. For this purpose, laboratory devices such as lock-in amplifier, photodetector and microwave source are broken down to their relevant functions and integrated on a (82 x 167) mm2 PCB with a STM32G491. Only two Rabi oscillations at different microwave powers need to be recorded in order to extract the Rabi frequency using the fast fourier transformation and calibrate the system. This allows the time of a pi pulse to be synchronized to the pulse length of the microcontroller.

Q 39.16 Wed 17:00 Aula Foyer

Diamond-based quantum sensing for neurosurgery — •Wickenbrock Arne — Johannes Gutenberg University Mainz, Germany

The DIAQNOS (Diamond-based quantum sensing for neurosurgery) project aims to develop a novel Quantum-Neuro Analyzer (QNA) to provide continuous and crucial information for tumor detection and functional diagnostics during neurosurgical procedures. The project utilizes diamond-based quantum sensors for preclinical studies on living human brain tissue. The goal is to implement a clinically deployable DIAQNOS-QNA, an imaging, magnetically sensitive quantum endoscope at the end of a multimodal light guide. This technology is intended to enhance the safety, precision, and efficiency of neurosurgical cancer therapy.

Q 40: Precision Spectroscopy of Atoms and Ions III (joint session A/Q)

Time: Thursday 11:00–13:00 Location: HS 1010

Q 40.1 Thu 11:00 HS 1010

Resolved sideband spectroscopy of cold mixed ioncystals of Ca^+ and Th^+ — •Azer Trimeche[1], Can Leichtweiss[1], Jonas Stricker[2,3], Valerii Andriushkov[1,2], Dmitry Budker[1], Christoph E. Düllmann[2,3,4], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany — [2]Helmholtz-Institut Mainz, Germany — [3]Department Chemie - Standort TRIGA, Johannes Gutenberg-Universität Mainz, Germany — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Thorium isotopes became of high interest in the search for new physics, and fundamental physics tests, because of their unique nuclear and atomic properties. The **T**rapping **A**nd **C**ooling of **T**horium **I**ons in **Ca**lcium crystals (TACTICa) project develops ion trapping and spectroscopic techniques for a precise determination of the nuclear moments, hyperfine intervals, and isotope shifts with different Th isotopes. For the production, we use two different sources: a recoil ion source [1] and a laser ablation source [2]. $^{232}Th^+$ ions are trapped in a $^{40}Ca^+$ crystal [2], and cooled down sympathetically by polarization gradient cooling [3]. We implement resolved sideband spectroscopy of mixed Ca-Th ion crystals as a starting point for resolved sideband ground state cooling of crystals with extreme charge-to-mass ratio difference and quantum logic spectroscopy of Th ions.

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

Q 40.2 Thu 11:15 HS 1010

High-resolution spectroscopy of fermium-255 at the RISIKO mass separator — •Mitzi Urquiza-González for the Fermium-Collaboration — Division HÜBNER Photonics, Hübner GmbH & Co KG, 34123 Kassel, Germany

Laser spectroscopy measurements can provide information about fundamental properties of both atomic and nuclear structure. Such measurements are of particular importance for the heaviest actinides and superheavy elements, where data is sparse. During the last measurement campaign at the RISIKO mass separator facility in the Institute of Physics in the Johannes Gutenberg University Mainz (JGU), nine successive samples, consisting of 108 to 109 atoms, were used to study the atomic and nuclear structure of ^{255}Fm (Z=100).

This presentation will focus on the hyperfine structure (HFS) of ^{255}Fm for two different excited levels, from which the hyperfine coupling constants have been determined.

Q 40.3 Thu 11:30 HS 1010

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

Molecular hydrogen ions (MHI) are a simple system allowing the comparison of high-precision measurements to state-of-the-art QED theory, testing the validity of the latter. At Alphatrap [1], we can isolate and confine a single MHI for months and perform high-precision spectroscopy using non-destructive quantum state detection.

I will present the results of hyperfine structure measurements on a single HD^+ ion. From these, the bound g factor of the constituent particles, as well as coefficients of the hyperfine Hamiltonian can be extracted. The latter are important for a better understanding of rovibrational spectroscopy performed on this ion, from which fundamental constants, such as $m_\mathrm{p}/m_\mathrm{e}$ are determined to highest precision [2].

We are currently upgrading our trap for single-ion rovibrational laser spectroscopy of MHI. The development of these techniques is one of the required steps towards spectroscopy of an antimatter $\overline{\mathrm{H}}_2^-$ ion [3].

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

Q 40.4 Thu 11:45 HS 1010

MMC Array to Study X-ray Transitions in Muonic Atoms — •Daniel Unger, Andreas Abeln, Thomas Elias Cocolios, Ofir Eizenberg, Christian Enss, Andreas Fleischmann, Loredana Gastaldo, Cesar Godinho, Michael Heines, Daniel Hengstler, Paul Indelicato, Daniel Kreuzberger, Klaus Kirch, Andreas Knecht, Jorge Machado, Ben Ohayon, Nancy Paul, Randolf Pohl, Katharina von Schoeler, Stergiani Marina Vogiatzi, and Frederik Wauters — for the QUARTET Collaboration

The QUARTET collaboration aims to improve the accuracy of absolute nuclear charge radii of light nuclei from Li to Ne. A proof-of-principle measurement with lithium, beryllium and boron has recently been performed at the Paul Scherrer Institute. Conventional solid-state detectors do not provide sufficient accuracy in the relevant energy range. We use a low temperature Metallic Magnetic Calorimeter (MMC) array for high-precision X-ray spectroscopy of low-lying states in muonic atoms. MMCs are characterized by a high resolving power of several thousand and a high quantum efficiency in the energy range of interest. We present the experimental setup and the performance of the detector used. We discuss the first preliminary spectra and systematic effects in this first measurement. The obtained data in combination with the achieved energy resolution and calibration should allow a more precise characterization of the muonic X-ray lines. With the knowledge gained, a significant improvement in the determination of nuclear charge radii is expected.

Q 40.5 Thu 12:00 HS 1010

Advancing RAdiation Detected Resonance Ionization towards more exotic nuclei — •Kenneth van Beek for the Radris Collaboration — TU Darmstadt

Experimental data on atomic and nuclear properties for exotic nuclei in the heavy actinide region ($Z \geq 100$) remains scarce up to date. The RAdiation Detected Resonance Ionization Spectroscopy (RADRIS) apparatus, located at GSI, Darmstadt, Germany, is employed to determine such quantities — such as energy levels, ionization potentials, moments, mean-square charge radii, and isotope shifts. Past measurements at RADRIS encompassed the study of $^{245,246,248-250,254}$Fm and $^{251-255}$No. In the current design of the setup the detection of laser ions via their α-decay for nuclei with half-lives in the order of several hours to tens of hours becomes impractical. This presentation will show already obtained results by RADRIS and how future improvements will increase the methods reach towards longer-lived nuclei. This will allow accessing, e.g., ^{246}Cf (35.7 h) and ^{252}Fm (25.39 h). The latter is of special interest, as it lies directly at the $N = 152$ shell gap in the fermium isotopic sequence, thus closing the gap between already studied isotopes on the neutron-rich and on the neutron-poor side.

Q 40.6 Thu 12:15 HS 1010

Electron Optical Systems for High-Resolution Electron Time-of-Flight Spectrometer — •Niclas Wieland[1], Lars Funke[2], Lasse Wülfing[2], Arne Held[2], Sara Savio[2], Markus Ilchen[1], and Wolfram Helml[2] — [1]Universität Hamburg, Insitut für Experimentalphysik — [2]Technische Universität Dortmund, Fakultät Physik

Angular streaking allows resolving the sub-femtosecond temporal structure of SASE free-electron laser pulses. A circularly polarized infrared laser imprints a phase-dependent momentum shift onto the photoelectron spectra of a gas target. Angle-resolving time-of-flight spectrometers can be used to resolve these. The latter devices typically consist of electron optics, a drift section, and a detector. Parameters such as energy resolution and energy-dependent transmission for the whole system can be determined by simulation. In this talk, we present the finalized simulation-supported spectrometer design used inside our new chamber for the SpeAR_XFEL project. Furthermore, we will introduce the possibility of adaptive electron optics in our spectrometer using the popular open-source computing platform FEniCSx to further increase the achievable resolution and transmission by applying optimizer-determined voltage sets to our optics. Gaining insight into electron trajectories using precise simulations appears to be an efficient way to improve the overall performance of such experiments-We present our progress in terms of electrode design and applied voltages for a 0-3 keV electron energy spectrum to further develop spectrometer research in this field.

Q 40.7 Thu 12:30 HS 1010

Calorimetric wire detector for monitoring atomic hydrogen beam — Christian Matthé, •Alec Lindman, and Sebastian Böser for the Project 8-Collaboration — Johannes Gutenberg Universität, Mainz

The Project 8 collaboration aims to determine the absolute neutrino mass with a sensitivity of 40 meV by measuring the tritium decay spectrum around the endpoint energy. For this level of precision it is necessary to use atomic tritium, since molecular tritium sensitivity is limited by the molecular final state distribution to about 100 meV.

A flux of $\approx 10^{19}$atoms/s from the source will be required to inject a beam with $\approx 10^{15}$atoms/s into the detection volume after cooling and state selection inefficiencies. For monitoring this beam, we have built a detector that uses a wire with a micrometer-scale diameter intersecting the beam on which a small fraction of the beam's hydrogen atoms recombine into molecules. The energy released heats the wire and produces a measurable change in its resistance. Such a detector is suitable for both development work and for minimally disruptive online monitoring in the final experiment. In this talk results will be presented on measurements of the atomic hydrogen fraction as well as the shape of the produced beam.

Q 40.8 Thu 12:45 HS 1010

Comparison of Sr lattice clocks from Japan, UK, and Germany — •Tim Lücke[1], Clock Teams[1,2,3,4,8], and Link Teams[1,2,5,6,7] — [1]PTB, Braunschweig, Deutschland — [2]NPL, London, UK — [3]RIKEN, Tokyo, Japan — [4]University of Tokyo, Tokyo, Japan — [5]LNE-SYRTE, Paris, France — [6]LPL, Paris, France — [7]RENATER, Paris, France — [8]University of Birmingham, Birmingham, UK

We present a measurement campaign investigating the agreement of state-of-the-art optical clocks from Japan and Europe. Two transportable Sr lattice clocks from RIKEN in Japan [1] and PTB in Germany were compared with the stationary Sr clocks at NPL in London [2] and PTB in Braunschweig. In addition to local comparisons an interferometric fiber [3] link was used to compare the clocks remotely. The data will also be analyzed with respect to chronometric leveling as a geodetic application.

[1] M. Takamoto *et al.*, Nat. Photonics **14**, 411-415 (2020).
[2] R. Hobson *et al.*, Metrologia **57** 065026 (2020).
[3] M. Schioppo *et al.*, Nat. Commun. **13**, 212 (2022).

Q 41: Ultra-cold Atoms, Ions and BEC II (joint session A/Q)

Time: Thursday 11:00–13:00 Location: HS 1098

Q 41.1 Thu 11:00 HS 1098

Realization of the ^{88}Sr fine-structure qubit: The building block for a 500-qubit quantum computer demonstrator (QRydDemo) — •Govind Unnikrishnan[1], Jennifer Krauter[1], Philipp Ilzhöfer[1], Ratnesh Kumar Gupta[1], Jiachen Zhao[1], Achim Scholz[1], Christian Hölzl[1], Aaron Götzelmann[1], Sebastian Weber[2], Nastasia Makki[2], Hans Peter Büchler[2], Jürgen Stuhler[3], Florian Meinert[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [3]Toptica Photonics AG, 82166 Gräfelfing, Germany

The QRydDemo project aims to realize a quantum computer demonstrator with 500 qubits based on the novel fine-structure qubit encoded in the metastable triplet manifold of ^{88}Sr, which enables fast gates (100 ns) and a long coherence time (10 ms). Here, we demonstrate the first step towards this goal by realizing preparation, readout and coherent operations on the fine-structure qubit. In addition to driving Rabi oscillations bridging an energy gap of 17 THz, we also carry out Ramsey spectroscopy with which we extract the coherence time T_2 in our system. A full quantum mechanical model is used to simulate our experiments by including noise sources to identify the main constraints limiting our coherence time and project improvements to our system in the immediate future.

Q 41.2 Thu 11:15 HS 1098

Dysprosium Quantum Gas Microscope — •Kevin Ng, Fiona Hellstern, Jens Hertkorn, Paul Uerlings, Lucas Lavoine, Ralf Klemt, Tim Langen, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

With quantum gas microscopy providing access to study particle interactions and correlations on the microscopic scale, engineering analogues to simulate and understand solid state systems with a high degree of control has become possible. Although single atoms can be trapped and imaged in optical lattices, most existing quantum gas microscopes trap and image atoms using light with relatively long wavelengths, and where only short-range contact interactions exist between atoms. Here, we present our progress toward building a quantum gas microscope with dysprosium atoms that will be trapped in lattices using ultraviolet ($\sim$ 360nm) light, where enhanced anisotropic dipolar interactions compete with tunable inter-site particle tunnelling and onsite interactions. Owing to the enhanced dipolar interaction strength between dysprosium atoms in optical lattices of such a short wavelength, our quantum gas microscope opens up the possibility to observe novel phases of matter in a variety of lattice geometries. Our planned experimental setup and initial steps toward characterising the trapping properties of dysprosium at 360nm will be presented.

Q 41.3 Thu 11:30 HS 1098

Stabilization of a paramatrically driven BEC: an open quantum system approach — •Larissa Schwarz, Simon B. Jäger, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

We theoretically analyze the effects of periodically modulated repulsive interactions in a Bose-Einstein condensate (BEC) that features intrinsic damping mechanisms. We derive a master equation describing the dynamics of the momentum modes of the BEC in the parameter regime of weak driving strengths. Above a threshold for the modulation strength we find that the BEC becomes unstable. Below this threshold the combination of damping and periodic driving guides the system into a stationary state that shows an enhancement of fluctuations for specific momentum modes that can be controlled by the driving frequency. We analyze the stationary state of these fluctuations, quantify the condensate depletion and analyze the squeezed and anti-squeezed quadratures generated by the parametric driving, emphasizing the possibility to generate non-classical states of matter.

Q 41.4 Thu 11:45 HS 1098

Collisional energy effects on atom-ion Feshbach resonances — •Fabian Thielemann[1], Joachim Siemund[1], Daniel Hönig[1], Wei Wu[1], Krzystof Jachymski[2], Thomas Walker[1,3], and Tobias Schaetz[1] — [1]Physikalisches Institut, Albert-Ludwigs Universität Freiburg — [2]Faculty of Physics, University of Warsaw — [3]Blackett Laboratory, Imperial College, London

Collisions between particles are at the heart of many physical and chemical processes. The ability to control them down to the single quantum level is crucial to understanding the constituents and their interaction. We use our hybrid setup to combine a single Ba^{+}_{138} ion with a cloud of ultra-cold, spin-polarized Li_6 near degeneracy. We investigate the transition from the classical to the quantum regime of collisions and show to what extent individual atom-ion Feshbach resonances of this combination depend on the collisional energy. With the help of a quantum recombination model, we make first steps towards distinguishing between resonances that occur due to different open-channel partial-wave contributions.

Q 41.5 Thu 12:00 HS 1098

A quantum-gas microscope for ultracold strontium atoms — Sandra Buob[1], Jonatan Höschele[1], Vasiliy Makhalov[1], •Antonio Rubio-Abadal[1], and Leticia Tarruell[1,2] — [1]ICFO - Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain

Quantum-gas microscopes offer novel observables to study quantum many-body systems, but have so far been mostly restricted to alkali atoms. Alkaline-earth species, like strontium, offer a range of desirable features, due to their electronic structure, which can significantly expand the toolbox of Hubbard-type quantum simulation.

In this talk, I will present the realization of site-resolved imaging of a quantum gas of bosonic strontium in a clock-magic optical lattice. We realize fluorescence imaging via the blue 461-nm transition and simultaneous attractive Sisyphus cooling via the narrow 689-nm intercombination line. From the raw fluorescence images, we are able to reconstruct the atomic occupation with fidelities above 95%. Our experiment opens the door to future microscopic studies of the dissipative Bose-Hubbard model, as well as SU(N) fermions.

Q 41.6 Thu 12:15 HS 1098

Phase-Stable Traveling Waves Stroboscopically Matched for Super-Resolved Observation of Trapped-Ion Dynamics — •Florian Hasse, Deviprasath Palani, Apurba Das, Frederike Doerr, Leon Goepfert, Ole Pikkemaat, Ulrich Warring, and Tobias Schaetz — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

We introduce an approach, creating and maintaining the coherence of four oscillators: a global microwave reference field, a polarization-gradient traveling-wave pattern of light, and the spin and motional states of a single trapped ion. The features of our method are showcased by probing the 140-nm periodic light pattern and stroboscopically tracing dynamical variations in position and momentum observables with noise floors of 1.8(2) nm and 8(2) $z\mu$Ns, respectively.

We are currently expanding our methods towards non-classical squeezed states to realize the transfer of spatial entanglements, present in multimode squeezed states, into the robust electronic degrees of freedom (DOF) of multiple ions. For this we switch the trapping potential of two $^{25}Mg^{+}$ ions fast enough to induce a non-adiabatic change of the ions' motional mode frequencies, preparing the ions in a squeezed state of motion, accompanied by the formation of entanglement in the ions' motional DOF. This is a promising ansatz to study analogs of physics of the early universe, as particle pair creation during cosmic inflation, and relativistic quantum effects, e.g., Hawking radiation.

A summary of our previous work is published on Arxiv: https://arxiv.org/abs/2309.15580

Q 41.7 Thu 12:30 HS 1098

Fractional angular momentum quantization in Atomtronic circuits — •Wayne Jordan Chetcuti[1], Juan Polo[1], Andreas Osterloh[1], and Luigi Amico[1,2,3] — [1]Quantum Research Center, Technology Innovation Institute, P.O. Box 9639 Abu Dhabi, UAE — [2]Dipartimento di Fisica e Astronomia and INFN-Sezione di Catania, Via S. Sofia 64, 95127 Catania, Italy — [3]Centre for Quantum Technologies, National University of Singapore 117543, Singapore

In this talk, I showcase the latest results for bosonic and fermionic matter-wave circuits in the context of Atomtronics. For attractively interacting bosons, the system sees the formation of bound states, which are the quantum analogs of bright solitons found in the mean-field regime. Considering the full many-body regime allows us access to a new phenomenology arising from the strong correlations in the system. Specifically, for a ring geometry pierced by a synthetic gauge field, we find that the angular momentum quantization per particle acquires fractional values depending on the number of particles constituting the bound state. The phenomenon of fractionalization manifests as new plateaus in the angular momentum and presents potentially important applications in the field of metrology and sensing. Analogous phenomenology is found in SU(N) fermionic systems in similar configurations. However, the physical origin of the angular momentum quantization present in these systems depends on the nature of the interactions, be they repulsive or attractive. The feature of fractionalization has promising applications to interferometry using these massive bound states in fermionic and bosonic systems.

Q 41.8 Thu 12:45 HS 1098

Magnetic field shielding and rotation stabilisation in the Einstein-Elevator — •Alexander Heidt — Institut für Transport- und Automatisierungstechnik, Hannover, Deutschland

There is an increasing focus on the exploration of space, its potential colonisation and the use of its advantages for fundamental physical research. To make this possible, technologies are required that work in microgravity. The Einstein-Elevator was developed and built out of the motivation to research technologies suitable for space. It is also able to simulate various gravity conditions. Numerous projects from various disciplines are currently being worked on, such as from mechanical engineering to develop new production processes and from physics to carry out basic research into atomic interferometry. One of these is the INTENTAS project, which aims to measure the entanglement of atoms in microgravity. The "spin-exchange collisions" method is used here, whereby weak magnetic field fluctuations can prevent such entanglement of atoms. In order to ensure this entanglement reliably, a magnetic field fluctuation of a few nanotesla is required. For this reason, a magnetic shield was designed as part of the project that suppresses magnetic field fluctuations in the Einstein-Elevator (10 *T) to a few nanotesla. On the other hand, the DESIRE project aims to find evidence of dark energy. However, the setup is sensitive to rotations, so the Einstein-Elevator has been extended with reaction wheels to compensate for any rotations that occur.

Q 42: Long-range Interactions

Time: Thursday 11:00–13:00 Location: HS 1015

Invited Talk Q 42.1 Thu 11:00 HS 1015

Theory of robust quantum many-body scars in long-range interacting systems — •Silvia Pappalardi — 77, Zulpicher Strasse, D-50937 Cologne

Quantum many-body scars are exceptional energy eigenstates of quantum many-body systems associated with violations of thermalization for special non-equilibrium initial states. Their various systematic constructions require fine-tuning of local Hamiltonian parameters. In this talk, I will show that the setting of long-range interacting quantum spin systems generically hosts robust quantum many-body scars. I will discuss that this is the combined effect of two ingredients: the integrability of the classical collective limit and the sufficiently strong long-range of the interactions. Broader perspectives of this work range from independent applications of the technical toolbox developed here to informing experimental routes to metrologically useful multipartite entanglement.

Q 42.2 Thu 11:30 HS 1015

Neural Network Quantum States for the Hofstadter Model with Higher Local Occupations and Long-Range Interactions — •Fabian Döschl[1,2], Felix Palm[1,2], Hannah Lange[1,2,3], Fabian Grusdt[1,2], and Annabelle Bohrdt[2,4] — [1]Ludwig-Maximilians-University Munich — [2]Munich Center for Quantum Science and Technology — [3]Max-Planck-Institute for Quantum Optics — [4]University of Regensburg

Neural network quantum states (NQS) have gained significant interest in current research due to their immense representative power. In this study, we show that RNN wave functions can be employed to study systems relevant to current research in quantum many body physics. Specifically, we employ a 2D tensorized gated RNN to explore the Hofstadter Hamiltonian with a variable local Hilbert space cut off. We benchmark the NQS against exact diagonalization for the Hofstadter Hamiltonian with on site interactions on a 6×6 square lattice. Remarkably, this method is capable of effectively identifying and representing the ground state. A further benchmark against DMRG for 12×12 systems will reveal phases that are hard to simulate with the RNN-NQS ansatz. Moreover, we demonstrate that NQSs are capable of capturing interactions over large distances, a task that is far from being solved by current methods. This technique is applied to a Hofstadter Hamiltonian with long-range interactions on a 12×12 square lattice. This work aims to enhance our understanding of representing strongly correlated quantum systems with NQS.

Q 42.3 Thu 11:45 HS 1015

Cavity induced quantum droplets — •Leon Mixa[1], Milan Radonjić[1,2], Axel Pelster[3], and Michael Thorwart[1] — [1]I. Institute of Theoretical Physics, Universität Hamburg, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Physics Department and Research Center OPTIMAS, University Kaiserslautern-Landau, Germany

Quantum droplets are formed in an interacting atom gas when quantum fluctuations stabilize the gas mechanically which would otherwise be unstable. Subjecting a condensate to interaction with a cavity is known to strongly couple the atomic and cavity fluctuations, creating long-range interactions and roton-like modes. We study the formation of quantum droplets in a three-dimensional homogeneous Bose-Bose mixture placed in an optical cavity. The internal transitions of the atoms are off-resonantly pumped by a beam transversal to the cavity axis. We find that cavity fluctuations influence droplet properties, such that changing the cavity parameters can be used for droplet tuning. Furthermore, cavity fluctuations can create necessary conditions for droplet formation even in the stable mean-field region of the bare mixture.

Q 42.4 Thu 12:00 HS 1015

Bragg Spectroscopy of a Dynamic Instability where two soft modes meet. — Alexander Baumgaertner, Gabriele Natale, •Justyna Stefaniak, Simon Hertlein, David Baur, Dalila Rivero, Tobias Donner, and Tilman Esslinger — ETH Zurich, Switzerland

The excitation spectrum of open many-body systems can give rise to various features e.g. dynamical instabilities and exceptional points. In our experiment, consisting of a Bose-Einstein condensate (BEC) coupled to a cavity mode, we realize two different superradiant crystals and perform Bragg spectroscopy to measure the excitation spectrum. Long-range interactions in quantum gases can give rise to an excitation spectrum with a roton-type minimum in the dispersion relation. In our case, we associate a roton-like mode with each of the superradiant crystals. By changing interaction strength, we observe how the excitation energies, the strength of the density-density correlations and the roton momentum are modified prior to the formation of one of the crystal phases. Dissipation introduces coupling between these two modes and can lead to an amplification of one and a dampening of the other mode. Additionally tuning the strength of the interactions, we found a regime, where two roton-type modes respond at the same energy. In this regime, the presence of dissipation introduces a coupling between these two models and finally leads to a dynamic instability of the system.

Q 42.5 Thu 12:15 HS 1015

Re-entrant phase transition in many-body Cavity QED — •Tom Schmit[1], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

We analyse theoretically self-organization of atoms that couple dispersively to an optical cavity and are subject to a transverse pump, in a configuration experimentally studied[1]. The transverse pump laser is blue-detuned w.r.t. the atomic transition, confining the atoms in the intensity minima of the generated optical lattice. The competition of pump and cavity field leads to self-organization of the atoms in an ordered pattern, giving rise to a re-entrant phase transition, such that by increasing the pump intensity above a critical value, one first observes a transition from disorder to self-organized and then, at larger values, again back to a disordered phase. Our theoretical model, founded on a mean-field ansatz, provides a description of the stationary state's phase diagram in relation to pump intensity and detuning from the cavity frequency, aligning well with experimental observations[1]. We show that stability of the ordered pattern is warranted when the scattered light interferes destructively with the pump at the atomic positions, effectively keeping the atoms in darkness. We discuss the connection between this phenomenon and *inverse melting*, observed in (classical) systems with repulsive and competing long-range interactions.

[1] P. Zupancic et al., Phys. Rev. Lett. **123**, 233601 (2019).

Q 42.6 Thu 12:30 HS 1015

Commensurate-incommensurate transition in frustrated Wigner crystals — •Raphaël Menu[1], Jorge Yago Malo[2], Vladan Vuletić[3], Maria Luisa Chiofalo[2], and Giovanna Morigi[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Universita di Pisa, Pisa, Italy — [3]Massachusetts Institute of Technology, Cambridge, USA

Geometric frustration in systems with long-range interactions is a largely unexplored phenomenon. In this work we analyse the ground state emerging from the competition between a periodic potential and a Wigner crystal in one dimension, consisting of a selforganized chain of particles with the same charge. This system is a paradigmatic realization of the Frenkel-Kontorova model with Coulomb interactions. We derive the action of a Coulomb soliton in the continuum limit and demonstrate the mapping to a massive (1+1) Thirring model with long-range interactions. The mean-field limit is a long-range antiferromagnetic spin chain with uniform magnetic field and predicts that the commensurate, periodic structures form a complete devil's staircase as a function of the charge density. Each step of the staircase correspond to the interval of stability of a stable commensurate phase and scales with the number N of charges as 1/ln N. This implies that there is no commensurate-incommensurate phase transition in the thermodynamic limit. For finite systems, however, the ground state has a fractal structure that could be measured in experiments with laser-cooled ions in traps.

Q 42.7 Thu 12:45 HS 1015

Ab initio simulation of dipolar Bose gases with the complex Langevin algorithm — •Philipp Heinen[1], Wyatt Kirkby[1,2], Lauriane Chomaz[2], and Thomas Gasenzer[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Physikalisches Institut, Universität Heidelberg

Bose-Einstein condensates (BECs) of atoms with a strong magnetic moment in their ground state, e.g. Erbium or Dysprosium, feature long-range dipolar interactions. These give rise to several peculiar phenomena that are absent from purely contact interacting Bose gases, notably rotonic excitations, supersolidity and quantum droplets. What makes them interesting from the theoretical point of view is that mean-field descriptions based on the Gross-Pitaevskii equation (GPE) fail to predict such states of matter and the effect of quantum fluctuations must be included. This can be done by adding an additional term to the GPE based on the perturbative Lee-Huang-Yang (LHY) correction or by performing ab initio path integral Monte Carlo (PIMC) simulations. The latter are, however, limited to several hundred atoms due to the high computational cost of the method, far below experimentally realistic particle numbers. An alternative is the equally fully exact complex Langevin (CL) algorithm whose computational cost is independent of the particle number and is thus suitable for simulating actual experimental settings from first principles. We will present the results of such simulations on both sides of the superfluid-supersolid transition of a dipolar BEC.

Q 43: Color Centers III

Time: Thursday 11:00–13:00 Location: Aula

Q 43.1 Thu 11:00 Aula

Long-lived quantum network memories using spin qubits in isotopically engineered diamond — •Kai-Niklas Schymik[1], Benjamin van Ommen[1], Conor Bradley[2], Takashi Yamamoto[1], and Tim Hugo Taminiau[1] — [1]QuTech an Kavli Institute of Nanoscience Delft, Delft University of Technology, 2628 CJ Delft, The Netherlands — [2]Pritzker School of Molecular Engineering, University of Chicago, Chicago, IL 60637, USA

Optically active spin qubits in solid-state materials, such as the NV center in diamond, are a promising platform for quantum computation distributed over a network. To increase the size and circuit depth of such a quantum network, e.g. beyond the state-of-the-art of three nodes, long-lived quantum memories in each node are desired. Recent work has identified Carbon-13 spin qubits in isotopically purified diamond as a promising candidate. In this work, we demonstrate control over isotope concentration in (111) CVD-grown diamond. At the targeted concentration of 0.05%, we show that memory qubits with kHz couplings can be addressed and measure long coherence times of the spin qubits. With a memory decoherence rate lower than possible entanglement rates between remote NV centers, these devices show promise for distributed computations using more than one entangled Bell pair.

Q 43.2 Thu 11:15 Aula

Photonic multipartite entangled state generation with group-IV color centers — •Gregor Pieplow[1], Yannick Strocka[1], Mariano I. Monsalve[2], Joseph H. D. Munns[3], and Tim Schröder[1] — [1]Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]University of Innsbruck, 6020 Innsbruck, Austria — [3]PsiQuantum, 94304 California Palo Alto, USA

In this work, we analyze the generation of large entangled photonic states, specifically multiphoton Greenberger-Horne-Zeilinger (GHZ) states and cluster states (CS) using group-IV color centers. These states are an essential resource in photonic quantum information applications, for example in measurement-based quantum computing and one-way quantum repeaters. Our research aims at providing a comprehensive analysis of the coherent control operations that are required for the creation of these resource states. The fidelity of these operations is critical; any compromise leads to a rapid degradation in the quality of the state. In particular, our work focuses on an optical Raman control scheme and microwave control. Both types of control operations enable single and two-qubit gates, which are crucial for the deterministic generation of resource states. Additionally, the study introduces a novel quality measure, which highlights the significance of fast, high-fidelity control techniques.

Q 43.3 Thu 11:30 Aula

Investigation of microwave spin control of unstrained negatively charged group-IV color centers in diamond — •Mohamed Belhassen[1], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

Microwave control is a standard technique for manipulating the electronic spin of diamond color centers owing to its advantages when implementing complex control sequences. For microwave control, a *dc* magnetic field is used to lift the spin degeneracy. An *ac* microwave pulse drives the system. Aligning the *dc* field parallel to the color center's symmetry axis and the *ac* field perpendicular to it has been commonly used in previous works. This configuration, although working well for the light color centers, has been shown to require high strain or large microwave powers for heavier ions, such as the tin- and lead-vacancy center. In addition to providing the theoretical framework to explain the requirement of strain for heavy defects in the above field configuration, we study the dependence of the Rabi frequency on the *dc* and *ac* fields orientations and strain. We provide analytical expressions and exact numerical simulations of the impact of strain and field orientations on microwave control. We find that strain can be rendered obsolete, while simultaneously producing higher Rabi frequencies for an alternative setup, where the *dc* field is aligned perpendicular to the color center symmetry axis and the *ac* field is aligned parallel to it. We show that this configuration is also efficient for the spin's optical initialization, readout and analyse resulting gate fidelities.

Q 43.4 Thu 11:45 Aula

Optically Detected Magnetic Resonance in Microdiamonds Embedded in Polymer Waveguides — •Marina Peters[1,2], Jonas Homrighausen[1], Tim Buskasper[2], Shqiprim Adrian Abazi[2], Daniel Wendland[2], Carsten Schuck[2], and Markus Gregor[1] — [1]Department of Engineering Physics, FH Münster University of Applied Sciences, Germany — [2]Department for Quantum Technology, University of Münster, Germany

Nitrogen vacancy centers in diamond hold great potential for quantum sensing applications. The challenge of integration can be addressed by using integrated photonics based on modern nanofabrication techniques. Here, we present optically detected magnetic resonance measurements from deterministically embedded microdiamonds with NV centers in polymer waveguides on silicon substrates. In combination with electrically conductive microstructures for microwave supply, this method of optical access provides the basis for scaling up to highly integrated on-chip sensors with excellent spatial magnetic resolution and sensitivity.

Q 43.5 Thu 12:00 Aula

Microscale NMR of hyperpolarized nuclei with NV centers in diamond — Luca Troise[1], •Nicolas Staudenmaier[2], Christoph Findler[2,3], Kirstine Berg-Sørensen[1], Fedor Jelezko[2], and Jan Henrik Ardenkjaer-Larsen[1] — [1]Department of Health Technology, Technical University of Denmark, 2800, Kongens Lyngby, Denmark — [2]Institute of Quantum Optics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [3]Diatope GmbH, Buchenweg 23, 88444 Ummendorf, Germany

We present a groundbreaking approach that combines nitrogen-vacancy (NV) center ensemble based quantum sensing with dynamic nuclear polarization to perform nuclear magnetic resonance (NMR) spectroscopy of picoliter samples. Traditional NMR spectroscopy suffers from poor sensitivity and requires larger sample volumes, typically in the milliliter range. However, the introduction of NV centers in diamond for NMR spectroscopy has revolutionized the field, enabling the analysis of unprecedented sample volumes. In our study, we utilize the dissolution dynamic nuclear polarization (dDNP) technique to hyperpolarize carbon nuclei, thereby overcoming previous sensitivity limitations and providing a pathway to high-resolution spectroscopy on molecules in dilute solutions. By integrating dDNP into NV-based NMR spectrometers, we not only promise to extend the capabilities of mass-limited NMR spectroscopy but also open up new avenues for research at the picoliter scale, including drug discovery, catalysis research, and single-cell studies.

Q 43.6 Thu 12:15 Aula

Laser noise compensation to enable high fidelity spin-photon gates — •Mara Brinkmann[1], Lennart Manthey[1], Donika Imeri[1,2], Rikhav Shah[1], Timo Eikelmann[1], Konstantin Beck[1], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Current research areas in quantum communication entail quantum networks, consisting of optically connected nodes, which can efficiently distribute entanglement. We use silicon-vacancy (SiV) color centers in diamond, which show great potential for optically coupled quantum processors. To address the probes at millikelvin temperature and achieve high fidelities for spin-photon quantum gates, we rely on pulsed weak laser light. Sideband-noise, such as relaxation oscillations, can result in off-resonant scattering, reducing the gate fidelity. Here we present our approach to optimize the temporal and spectral properties of the laser light, employing mode cleaner cavities. The spin-photon gates can subsequently be used to create high-fidelity entanglement between remote quantum processors.

Q 43.7 Thu 12:30 Aula

Optimization of nuclear spin control with germanium vacancy centre in diamond at mK temperatures — •Nick Grimm, Katharina Senkalla, Philipp Vetter, and Fedor Jelezko — Institute for Quantum Optics, Ulm University

Long-distance quantum communication requires a platform which allows to collect, store and process quantum information. Promising candidates for such quantum nodes are the negatively charged group-IV defects in diamond as they provide an efficient spin-photon interface with high photon flux, long coherence times and high-fidelity single qubit gates. Moreover, addressing of proximal nuclear spins can be used for computational purposes or act as memory qubits. Here we demonstrate for the first time the coherent control of a hybrid register of a negatively charged germanium vacancy centre (GeV) electron spin and a strongly coupled single ^{13}C nuclear spin with excellent coherence properties at mK temperatures. We show initialisation and readout of the nuclear spin using a SWAP gate with the optically addressable GeV electron spin. Applying optimized microwave and radiofrequency pulses on the electron and nuclear spin, respectively, allows to reach increased fidelities. The realization of this fully controlled two-qubit register is laying the groundwork for the implementation of quantum repeaters.

Q 43.8 Thu 12:45 Aula

Spin-phonon entanglement in SiC optomechanical quantum oscillators — •Ruoming Peng[1], Xuntao Wu[2], Durga Dasari[1], and Joerg Wrachtrup[1] — [1]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany — [2]Pritzker School of Molecular Engineering, University of Chicago, Chicago IL 60637, USA

Scaling up quantum systems, especially solid-state spins, presents a significant challenge in the field of quantum information science. In this study, we propose a hybrid spin-phonon architecture based on spin-embedded optomechanical crystal (OMC) cavities. This architecture combines integrated photonic and phononic accesses, allowing for the entanglement of multiple spins. Remarkably, this hybrid spin-optomechanical system can offer a coupling of the spin to the vibration mode of simulated Silicon Carbide OMC cavities approaching MHz in a Raman-facilitated mechanism, enabling a fast and efficient spin-phonon entanglement with fidelity of 98%. By incorporating the Stimulated Raman Adiabatic Passage (STIRAP) protocol into the coupled tripod-phonon system, a two-qubit Controlled-Z gate with 97% fidelity is implemented by engineering the non-vanishing geometry phase in a strongly coupled spin-phonon dark state basis, which is robust against the dominant loss from the excited state and allow for full connection of spins through the cavity phonon. Our work establishes a crucial platform for exploring the spin entanglement with potential scalability in addition to the optical link, which opens the path to investigate quantum acoustics in hybrid solid-state systems

Q 44: Quantum Information II

Time: Thursday 11:00–13:00 Location: HS 1199

Q 44.1 Thu 11:00 HS 1199

A fine structure qubit encoded in metastable strontium trapped in an optical lattice — •Sebastian Pucher[1,2], Valentin Klüsener[1,2], Jan Geiger[1,2], Felix Spriestersbach[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

The development of scalable, high-fidelity qubits is a key ongoing research challenge in quantum information science, with neutral atoms trapped in optical lattices being a promising candidate. Here, we present spectroscopy of a new Raman qubit using long-lived metastable states in Sr. This architecture enables fast single- and two-qubit gates. We coherently transfer the atoms from the ground state to the metastable $^3P_2$ state and couple this state to the $^3P_0$ state using a two-photon Raman transition. We demonstrate high-fidelity Rabi oscillations of atoms trapped in an optical lattice and study the coherence times in our system. This work establishes metastable Sr as a promising candidate for realizing quantum computing.

Q 44.2 Thu 11:15 HS 1199

Optimization of Optical Spin Gates for negatively charged Group-IV Colour Centers in Diamond — •Yannick Strocka, Gregor Pieplow, and Tim Schröder — Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany

The control of the spin of negatively charged Group-IV colour centers in diamond plays an important role in various applications such as quantum computers and quantum repeaters. These applications require high fidelity control of the spin qubit, which is formed by the two lowest lying energy eigenstates of the system. Typically a microwave control is used to manipulate the qubit. In this work, however, we theoretically study the control using optical means. The optical control is composed of two laser pulses, whose frequencies are detuned from the transition between the lowest lying ground and excited state. This way a, so called, Raman spin gate is created. Optical pulses have the advantage that they allow the control over a much larger range of splittings. Under idealized assumptions perfect gates are in theory possible. The details of the color centers, however, are such that fast phononic decay greatly impacts the gate fidelity: Spurious population in the highest lying states, reduce the fidelity of the Raman spin gates due to spontaneous phononic relaxation. In order to counteract that decoherence effect any population in the levels affected must be minimized. In this work we combine gradient-free optimization such as the Nelder-Mead algorithm and gradient-based methods like Grape and Krotov to achieve this goal

Q 44.3 Thu 11:30 HS 1199

Enhancing the purity of single photons in parametric down-conversion through simultaneous pump-beam and crystal-domain engineering — •Baghdasar Baghdasaryan[1,2], Fabian Steinlechner[1,2,4], and Stephan Fritzsche[1,3,5] — [1]FSU Jena — [2]IAP Jena — [3]HI Jena — [4]Fraunhofer IOF, Jena — [5]TPI, Jena

Spontaneous parametric down-conversion (SPDC) has shown great promise in the generation of pure and indistinguishable single photons. Photon pairs produced in bulk crystals are highly correlated in terms of transverse space and frequency. These correlations limit the indistinguishability of photons and result in inefficient photon sources. Domain-engineered crystals with a Gaussian nonlinear response have been explored to minimize spectral correlations. Here, we study the impact of such domain engineering on spatial correlations of generated photons. We show that crystals with a Gaussian nonlinear response reduce the spatial correlations between photons. However, the Gaussian nonlinear response is not sufficient to fully eliminate the spatial correlations. Therefore, the development of a comprehensive method to minimize these correlations remains an open challenge. Our solution to this problem involves simultaneous engineering of the pump beam and crystal. We achieve purity of single-photon state up to 99 % without any spatial filtering. Our findings provide valuable insights into the spatial waveform generated in structured SPDC crystals, with implications for applications such as boson sampling.

Q 44.4 Thu 11:45 HS 1199

Phase compensation for free space continuous variable quantum key distribution using unscented Kalman filter — •Wenjia Elser[1,2], Stefan Richter[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, Germany

Continuous variable quantum key distribution (CV-QKD) is typically conducted in a very low signal to noise ratio (SNR) regime associated with the quantum signal. As a result, the tracking and compensation of laser phase noise is critical to reducing excess noise in the signal. This work concerns the phase compensation of our experiment data over an urban free-space CV-QKD link. Implementing time-division multiplexed reference pulses to provide a sufficiently high SNR reference for laser phase tracking, we apply an unscented Kalman filter (UKF) on the phase estimation and investigate its effect on the quantum signal excess noise.

Q 44.5 Thu 12:00 HS 1199

Detection of spin order from collective photon scattering — •Benjamin Zenz[1], Ansgar Schaefer[1], Maurizio Verde[1], Zyad Shehata[2], Stefan Richter[2], Joachim Von Zanthier[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Mainz, Germany — [2]Institut für Physik, Erlangen, Germany

Ion traps are ideal candidate platforms for quantum simulators of interacting spin systems by encoding the effective spins within the internal energy levels of the ions. This talk presents a way to efficiently read out the spin order of an $^{40}Ca^+$ ion crystal in a segmented Paul trap by detecting collective, coherent photon scattering in the far-field. In the past, we employed far-field photon detection to reveal the ion's position [1]. Now, we utilize a two-photon process involving a narrow quadrupole transition near 729 nm and a dipole transition near 854 nm to achieve background-free detection of 393 nm photons. Additionally, this scheme enables a spin-selective detection, such that we can determine the spin order of an ion crystal and investigate it's temporal evolution. Our experimental results are obtained with linear crystals of 3,4 and more ions and fit the theory expectations.

[1] S. Wolf, J. Wechs, J. von Zanthier, and F. Schmidt-Kaler Phys. Rev. Lett. 116, 183002 (2016)

Q 44.6 Thu 12:15 HS 1199

Determination of free-electron density matrices using heterodyne detection and maximum likelihood estimation — •Hao Jeng[1,2], Jan-Wilke Henke[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, D-37077 Göttingen, Germany — [2]University of Göttingen, D-37077 Göttingen, Germany

Free electrons interacting with light are known to scatter into superpositions of momentum states [1], but existing methods to determine these density matrices are limited in accuracy [2]. We have developed a reconstruction algorithm based on maximum likelihood estimation that circumvents these issues, and we have used this method to verify the formation of attosecond electron pulses. We have also developed an analogue of optical heterodyne detection for free electrons, which we use to examine the quantum states produced from interactions with light in a waveguide. These techniques greatly simplify the measurement and reconstruction of free-electron states, opening up new routes of investigation into the quantum interaction between free electrons and light.

[1] Feist et al., Nature 521, 200 (2015).

[2] Priebe et al., Nature Photonics 11, 793 (2017).

Q 44.7 Thu 12:30 HS 1199

Free-electron cavity-photon interaction via integrated photonics — •Germaine Arend[1,2], Yujia Yang[3,4], Armin Feist[1,2], Guanhao Huang[3,4], Jan-Wilke Henke[1,2], Arslan Sajid Raja[3,4], F. Jasmin Kappert[1,2], Rui Ning Wang[3,4], Hugo Lourenco-Martins[1,2], Junqiu Liu[3,4], Ofer Kfir[1,2], Tobias J. Kippenberg[3,4], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, D-37077 Göttingen, Germany — [2]Georg-August-Universität Göttingen, D-37077 Göttingen, Germany — [3]Swiss Federal Institute of Technology Lausanne (EPFL), CH-1015 Lausanne, Switzerland — [4]Center for Quantum Science and Engineering, EPFL, Lausanne, Switzerland

Quantum communication largely relies on the generation of photon pairs as well as their interactions with different quantum systems. Coupling of single photons with free electrons, a potential candidate, has been hampered due to limited control over the optical states and the lack of coincidence detection capabilities. Here, we generate electron-photon pairs by inelastic scattering of free electrons with the evanescent optical field of a Si_3N_4 resonator and detect the generated photons, as well as the corresponding electron energy loss. The temporal correlation of both particles demonstrates a distinct peak of coincidence events, highlighting their common origin [1]. The connection between energy loss and photon number enables post-selection onto single, or even n-photon states. This setup enables the exploration of new experimental concepts in free-electron quantum optics. [1] A. Feist, G. Arend et al., Science 377, 777 (2022)

Q 44.8 Thu 12:45 HS 1199

Mesoscopic quantum dynamic in X-ray waveguides — •Petar Andrejic[1], Leon Lohse[2,3], and Adriana Palffy[4] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Deutsches Elektronen-Synchrotron — [3]Georg-August-Universität Göttingen — [4]Julius-Maximilians-Universität Würzburg

Grazing incidence X-ray waveguides have become a well established platform for X-ray quantum optics. In these systems, X-rays are scattered resonantly by Mössbauer transitions in atomic nuclei, leading to a collective interaction between the indistinguishable nuclei and the waveguide field.

We show that driving such X-ray waveguides at forward incidence allows for direct excitation of multiple guided modes, with centimetre scale attenuation lengths [1]. In this regime, the embedded Mössbauer nuclei absorb and emit collectively into a super-position of these modes, with the resultant radiation field displaying pronounced interference beats on a micrometre scale. We show that this interference pattern leads to sub-radiance of the nuclear ensemble, with suppression of the dynamical beat at certain critical waveguide lengths. We also consider structuring the nuclear ensemble into micrometre scaled patches, and show that it is feasible to engineer the resultant internuclear coupling to create mesoscopic and hopping models [2], with potential for applications in quantum simulation and experimental exploration of mesoscopic quantum dynamics and topological physics.

[1] https://doi.org/10.1364/opticaopen.24028686.v2

[2] https://doi.org/10.48550/arXiv.2305.11647

Q 45: Quantum Metrology for Fundamental Physics

Time: Thursday 11:00–13:00 Location: HS 1221

Invited Talk Q 45.1 Thu 11:00 HS 1221

Quantum Sensing in Space for Fundamental Physics and Applications — •Naceur Gaaloul — Leibniz University of Hanover, Institute of Quantum Optics, Hanover, Germany

Space-borne quantum technologies, particularly those based on atom interferometry, are heralding a new era of strategic and robust space exploration. The unique conditions of space, characterized by low-noise and low-gravity environments, open up diverse possibilities for applications ranging from precise time and frequency transfer to Earth Observation and the search of new Physics.

This contribution focuses on recent mission concepts utilizing quantum-gas sensors. The first mission, Space-Time Explorer and Quantum Equivalence Principle Space Test (STE-QUEST), introduces a dual-species atom interferometer operating over extended durations. This mission aims to tackle fundamental questions in Physics, such as testing the universality of free fall with unprecedented accuracy (better than one part in 10^{-17}), exploring various forms of Ultra-Light Dark Matter, and scrutinizing the foundations of Quantum Mechanics.

The second satellite mission is the CARIOQA pathfinder, recently endorsed by the European Commission. It is set to lay the groundwork for a space Geodesy mission, utilizing atom accelerometers to map temporal variations in Earth's gravity field.

To conclude, this presentation offers an overview of recent experimental results from orbital quantum laboratories, highlighting the cutting-edge advancements in the field of space-based quantum technologies.

Q 45.2 Thu 11:30 HS 1221

Polarization dynamics in a self-compensated comagnetometer for dark matter searches — •Daniel Gavilan-Martin[1,2], Mikhail Padniuk[3], Emmanuel Klinger[1,2,4], Grzegorz Lukasiewicz[3], Szymon Pustelny[3], Derek Jackson Kimball[5], Dmitry Budker[1,2,6], and Arne Wickenbrock[1,2] — [1]Helmholtz-Institut Mainz — [2]Johannes Gutenberg-Universität Mainz — [3]Marian Smoluchowski Institute of Physics, Jagiellonian University in Krakow — [4]Université de Franche-Comté — [5]Department of Physics, California State University East Bay, Hayward — [6]Department of Physics, University of California, Berkeley

Self-compensated comagnetometers, employing overlapping samples of spin-polarized alkali and noble gases (for example K-3He) are promising sensors for exotic beyond-the-standard-model fields and high-precision metrology such as rotation sensing. We propose and demonstrate a general method to calibrate the response of an atomic comagnetometer, to any possible perturbation of the atomic spins. The method uses a convenient, easy-to-implement protocol that is experimentally verified by successfully using it to predict the comagnetometer response to rotations. Furthermore, I will discuss the prospects of a search for gradient coupled axion-like dark matter conducted with such machine.

Q 45.3 Thu 11:45 HS 1221

Parity violation in atomic ytterbium: a progress report — •Stefanos Nanos, Iraklis Papigkiotis, Timoleon Avgeris, and Dionysios Antypas — Department of Physics, University of Crete, GR-70013 Heraklion, Greece

Small-scale tabletop experiments are emerging as a complement to their large-scale high-energy-physics counterparts conducted in large facilities, for studies on fundamental physics. Specifically, atomic parity violation (APV) serves as a gateway to understanding the effects of weak interaction in atoms. Recent observations on how the APV effect varies among a chain of ytterbium (Yb) isotopes motivate the implementation of this method as a versatile probe of nuclear and particle physics.

In this spirit, our team has initiated construction of an atomic beam apparatus, focusing on detecting isotopic variation of APV in Yb. The new setup is currently under development at the Physics Department of the University of Crete in Greece, with the purpose of measuring the Yb $6s^2\ ^1S_0 \rightarrow 5d6s\ ^3D_1$ optical transition at 408 nm. The project aims to significantly expand existing approaches, through high-precision APV measurements, with a focus on probing the neutron distributions in the Yb nuclei. These investigations seek to address questions related to the size of neutron-rich nuclei and neutron stars. Moreover, the method will serve as a probe of physics beyond the Standard Model, involving studies of electron-nucleon interactions which would be mediated by additional Z bosons.

Q 45.4 Thu 12:00 HS 1221

Dark Energy Detection at the Einstein-Elevator — •Charles Garcion[1], Magdalena Misslisch[1], Sukhjovan Gill[1], Ioannis Papadakis[2], Sheng-wey Chiow[3], Nan Yu[3], and Ernst Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Ferdinand Braun Institut, Humboldt Universität Berlin, Germany — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, United States of America

Investigating dark energy, which constitutes 70% of the universe's energy and drives its accelerated expansion, remains a fundamental challenge. Scalar fields with screening mechanisms such as chameleon, symmetron and galileon have been proposed as potential explanations for dark energy. Cold atom experiments, particularly in chameleon and symmetron parameter constraints, have been valuable but face limitations due to the uncertainties on the gravity interactions between test masses and atoms.

This presentation discusses the collaborative D3E3/DESIRE project between JPL and Leibniz University Hannover. Utilizing atom interferometers in the microgravity environment of the Einstein-Elevator, the project aims to modify the scientific payload from the MAIUS-1 sounding rocket mission. This modification involves implementing a periodic test masse and multi-loop atom interferometers to enhance dark energy model constraints.

The DESIRE project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics Affairs and Climate Action (BMWK) under grant number 50WM2155

Q 45.5 Thu 12:15 HS 1221

Reflective atom interferometer and its applications — •Johannes Fiedler and Bodil Holst — Department of Physics and Technology, University of Bergen, Norway

The field of atom interferometry has experienced significant growth in recent decades, finding applications in diverse areas, from measuring fundamental physics constants to precision atomic clocks. Many applications involve the use of cold atoms or Bose-Einstein condensates, employing laser pulses to split the atomic wave function. In contrast, transmission interferometers with thermal atoms utilize dielectric objects [1] or a standing laser field [2] for beam splitting, limiting the separation to a few milliradians [3]. This presentation introduces a reflective atom interferometer scheme, leveraging surface diffraction between two parallel plates to achieve a large-angle separation of the wave function [4]. The talk covers a feasible interferometer setup, showcases expected interference patterns, and outlines optimal designs for applications in acceleration measurements and velocity selection.

[1] N. Gack et al. Phys. Rev. Lett. 125, 050401 (2020). [2] S. Eibenberger et al. Phys. Rev. Lett. 112, 250402 (2014). [3] C. Brand et al. Nature Nanotechnology 10, 845 (2015). [4] J. Fiedler et al. Phys. Rev. A 108, 023306 (2023).

Q 45.6 Thu 12:30 HS 1221

Theory of multi-axis atom interferometric sensing for inertial navigation — •Christian Struckmann, Knut Stolzenberg, Dennis Schlippert, and Naceur Gaaloul — Leibniz University Hannover, Institute of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany

Quantum sensors based on the interference of matter waves provide an exceptional measurement tool for inertial forces, and are considered next generation accelerometers for applications in geodesy, navigation, or fundamental physics due to the absence of drifts. However, conventional atom interferometers are only able to measure inertial forces along one single axis, resulting in one acceleration and one rotation component. To determine the motion of a moving body, an inertial measurement unit needs to measure the acceleration and rotation of the body along three perpendicular directions. Extending this atom interferometeric measurement scheme to multiple components would normally require the subsequent measurement along a differently oriented axis.

In this contribution, we present our theory and simulation efforts based on experimental schemes enabling three dimensional sensing using simultaneously operated single-axis atom interferometers. We detail the sensitivity and dimensionality scaling of the measurement as well as its potential and improvement avenues.

This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 45.7 Thu 12:45 HS 1221

Scenario building for Earth Observation Space Missions Featuring Quantum Sensors — •Gina Kleinsteinberg, Christian Struckmann, Naceur Gaaloul, and for the CARIOQA Consortium — Institute of Quantum Optics, Leibniz University Hanover, Welfengarten 1, 30167 Hanover, Germany

Being extremely sensitive to accelerations and rotations with high stability at low frequencies, atom interferometer configurations offer a versatile approach not only for Fundamental Physics research but also for Earth Observation. The latter is currently gaining more and more significance, as consequences of climate change, e.g. sea level rise and changes in water mass distributions are directly reflected in Earth's gravity field. In order to increase the maturity of quantum sensors in space, the European Commission envisages a quantum pathfinder mission, CARIOQA-PMP (Cold Atom Rubidium Interferometer in Orbit for Quantum Accelerometry - Pathfinder Mission Preparation), to be launched by the end of this decade. In this contribution, we present a simulation tool capable to analyse the mission scenarios for the quantum pathfinder as well as for the follow-on full-fledge quantum gravimetry mission. The mission scenario is developed in close cooperation with the geodesy community within the CARIOQA-PMP project from the classical satellite simulations, the quantum measurement and finally the recovery of the gravity field from the interferometer signal. This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 46: Lasers I

Time: Thursday 11:00–13:00 Location: HS 3118

Q 46.1 Thu 11:00 HS 3118

High Power UV Laser Systems for Bunched Beam Laser Cooling — •Benedikt Langfeld, Jens Gumm, Tamina Grunwitz, and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik

Laser cooling of bunched relativistic ion beams has been shown (e.g. at GSI Helmholtzzentrum) to be a powerful technique to generate ion beams with small emittances and narrow longitudinal velocity distributions. For highly relativistic (large γ-factors) and intense heavy-ion beams, laser cooling will be very efficient and cooling times of the order of seconds are expected. For these reasons, laser cooling will be the only available cooling method at the planned heavy-ion synchrotron SIS100 at FAIR.

In this talk, we discuss the principle of bunched beam laser cooling using multiple laser beams. We will give an overview of two laser systems that will be used at the SIS100, namely one continuous-wave (cw) laser system and one pulsed picosecond laser system. At the TU Darmstadt, the cw master-oscillator-power-amplifier UV laser system - with two SHG cavities - and the tunable high repetition rate (1-10 MHz) pulsed UV laser system - with a continuously adjustable pulse duration between 50 and 735 ps - are being developed. With these systems, we achieved very high UV output powers of over 2W UV (cw system) and over 4W average power (pulsed system).

Q 46.2 Thu 11:15 HS 3118

Two-cycle laser pulse at 1600 nm from a compact fiber-feedback OPO and OPA combination at 76 MHz repetition rate — •Johann Thannheimer, Abdullah Alabbadi, Tobias Steinle, and Harald Giessen — University of Stuttgart

Compact and powerful few-cycle sources between 1 μm and 2 μm are required to generate mid-infrared light for spectroscopy via intra-pulse difference frequency generation, as well as for ultrafast metrology via electro optic sampling. We demonstrate fiber-based compression down to two optical cycles (12 fs) at 1600 nm with an average power of 570 mW and a repetition rate of 76 MHz. We use an Yb-based pump laser for an optical parametric oscillator which is subsequently amplified to the watt scale using an optical parametric amplifier. The nonlinear frequency broadening and anomalous dispersion which is required for pulse compression, is realized by just coupling the light into a 42-mm-long common single mode fiber. FROG measurements confirm that our system realizes few cycle pulses based on an extremely compact, stable, and low-noise solid-state laser system.

Q 46.3 Thu 11:30 HS 3118

A single-stage dispersion-controlled multipass cell setup to efficiently drive resonant dispersive wave emission. — •Ammar bin Wahid[1], Laura Silletti[1], Teodora F. Grigorova[2], Lorenzo Pratolli[1], Christian Brahms[2], Esmerando Escoto[1], Prannay Balla[1,3], Supriya Rajhans[1,3], Katinka Horn[1], Lutz Winkelmann[1], Vncent Wanie[1], Andrea Trabattoni[1,4], Christoph M. Heyl[1,3], John C. Travers[2], and Francesca Calegari[1] — [1]DESY, Germany — [2]Heriot-Watt University, United Kingdom — [3]Helmholtz-Institute Jena, Germany — [4]Leibniz Universität Hannover, Germany

Yb-based lasers are characterised by their ability to operate at high average power and high repetition rates. However, they are limited by relatively long Fourier transform limit pulse duration, typically spanning from 100 fs up to the few ps regime. To overcome these challenges, multi-pass cells (MPCs) are becoming an increasingly attractive solution. They allow operation at high peak and average power while maintaining high efficiencies (>90%), high compression ratios, compact setup sizes and excellent beam quality. [1][L. Silletti et al.Optics Letters, 48(7), 1842-1845]. Here we present tunable 3fs transform-limited deep-UV light generation by driving resonant dispersive waves (RDWs) in an argon-filled hollow core fibres [2][J.C. Travers et.Nat. Photonics 13, 547-554 (2019)] cascaded by a single-stage dispersion-engineered MPC, which is capable of compressing 150-fs pulses to sub-20-fs durations with scalability from 1kHz up to 200kHz.

Q 46.4 Thu 11:45 HS 3118

8-Fold Energy Upscaling by Divided-Pulse Spectral Broadening in a Multi-Pass-Cell — •Henrik Schygulla[1,2], Nayla Jimenez[1,3,4], Yujiao Jiang[1], Hüseyin Çankaya[1], Ingmar Hartl[1], and Marcus Seidel[1,3,4] — [1]DESY, Hamurg, Deutschland — [2]Uni Hamburg, Deutschland — [3]Helmholtz Institute Jena, Deutschland — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Deutschland

Multi-pass-cells (MPC) offer an excellent spectral broadening method, but a current challenge is its peak power scalability [1]. To resolve this, we divided the input pulse [2] into 8 replicas and demonstrated a corresponding increase of pulse energy after nonlinear compression.

The used laser generated 208fs pulses at 1030nm with a pulse energy of up to 140uJ. The input pulse was divided into 8 replicas using 3 calcite crystals and sent through the MPC for spectral broadening to a 45fs bandwidth limit. Afterwards, the replicas were recombined with an identical set of crystals and compressed via chirped mirrors. A duration of 49fs after compression was measured by FROG. The nonlinear compression performance of a single 17uJ pulse and the 140uJ pulse train was compared: The polarisation cleaning losses for the divided-pulse setting were 5%, the pulse duration remained the same.

These results enable switching laser repetition rates for FLASH pump-probe experiments [3] without compromising the pulse duration.

[1] Viotti et al. Optica 9, 197 (2022); [2] Stark et al. J. Phys. Photonics 4, 035001 (2022); [3] Viotti et al. Rev. Sci. Instr. 94, 023002 (2023)

Q 46.5 Thu 12:00 HS 3118

Intra-Cavity Control of Dual-Comb Soliton Motion inside a single Fiber Laser — •Julia A. Lang[1], Sarah Hutter[2], Alfred Leitenstorfer[2], and Georg Herink[1] — [1]Experimental Physics VIII - Ultrafast Dynamics, University of Bayreuth, Bayreuth, Germany — [2]Department of Physics and Center for Applied Photonics, University of Konstanz, Konstanz, Germany

Ultrafast lasers can exhibit dynamic sequences of multiple solitons. However, understanding and controlling their dynamics or utilizing them practically remains challenging. In this contribution, we introduce a new method for the precise control of relative soliton motion. By employing intra-cavity acousto-optic modulation, we selectively modulate single pulses out of two interlaced harmonically mode-locked frequency combs in an all-fiber Er:fiber laser. Upon external stimuli, the trajectories exhibit rapid and deterministically adjustable behaviour as a result of the interplay of ultrafast nonlinearity and laser gain dynamics. Based on these findings, we demonstrate fast all-optical scanning of picosecond pump-probe delays and programmable free-form soliton trajectories [1].

[1] Lang, J. A., Hutter, S. R., Leitenstorfer, A., & Herink, G. (2023). Controlling Dual-Comb Soliton Motion inside a single Fiber Laser Cavity. arXiv preprint arXiv:2308.13472.

Q 46.6 Thu 12:15 HS 3118

Optical pumped 10μm amplifier — •Bernd Witzel, Paul-Émile Chantrel, Bernard Sévigny, and Michele Piché — Centre d'Optique Photonique et Laser (COPL) and Département de Physique de Génie Physique et d'Optique Université Laval, Québec, Québec, G1V 0A6,Canada

We have demonstrated a high-energy, single-crystal Optical Parametric Oscillator (OPO) pumped directly by a Nd-YAG laser operating at 1064 nm. In our study, we compare this system to a standard Master Oscillator Power Amplifier (MOPA) setup equipped with one OPO and four amplification stages. We achieved pulse energies of 90 mJ at 2 μm for the high-energy OPO and 115 mJ for the MOPA system. The duration of both the signal and idler beams is approximately seven nanoseconds. Both systems allow for wavelength tuning between 1.9 μm and 2.4μm. We aim to explore the feasibility of pumping a 10 μm amplifier and present our initial findings regarding this amplification. The active gas employed in this amplifier is CO_2 under high-pressure. This system is designed for the amplification of 10 μm ultra-short laser pulses with a duration of 200 fs.

Q 46.7 Thu 12:30 HS 3118

Ultraviolet supercontinuum generation using a differentially-pumped glass chip — •Josina Hahne[1,2], Vincent Wanie[3], Pasquale Barbato[4,5], Sergey Ryabchuk[1,2], Ammar Bin Wahid[3], David Amorim[3], Erik P. Månson[3], Andrea Trabattoni[5,6], Roberto Osellame[5], Rebeca Martínez Vázquez[5], and Francesca Calegari[1,2,3] — [1]Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging — [3]CFEL, Hamburg — [4]Politecnico di Milano — [5]CNR-INF, Milano — [6]Leibniz Universität Hannover

UV pulses with a duration of a few- or sub-femtosecond durations are of great interest in the field of ultrafast spectroscopy, since they provide access to the UV-induced electron dynamics in biologically relevant molecules. Sub-3-fs UV pulses have previously been generated by third-harmonic generation in gas cells or resonant dispersive wave emission in hollow capillaries. Here, we present a compact glass chip design which combines a gas cell with two differential pumping stages, providing high gas confinement, to minimize the reabsorption of the generated UV pulses and preserve their temporal duration. The resulting UV pulse energy reaches up to 0.8 uJ in neon (0.2% conversion efficiency). The generated spectra spann from 200 to 325 nm, supporting transform limit durations of 2.1 fs in argon and 1.9 fs in neon. To gain further insight into the nonlinear process, numerical simulations have been performed. Ionisation has been found to be key for the exceptional broadening of the UV pulses due to the spatio-temporal reshaping of the driving field as well as plasma blue shifting.

Q 46.8 Thu 12:45 HS 3118

NOPA rainbow: 10 fs regime pulses tunable over more than an octave — •Ferdinand Bergmeier and Eberhard Riedle — Lehrstuhl f. BioMolekulare Optik, Fakultät f. Physik, LMU München

We combine a contemporary Yb-based 250 fs industrial-grade pump laser with a newly devised and comprehensively engineered non-collinear optical parametric amplifier (NOPA). The NOPA employs easily interchangeable 515 and 343 nm pumping, facilitating fundamental tunability from 390 to 950 nm without any gaps. Output pulse energies of some uJ are reached in a single amplification stage with a clean Gaussian beam shape. The repetition rate can be varied between 1 and 200 kHz without adjustments at constant pulse parameters. A single stage of second harmonic generation (SHG) extends this range down to below 220 nm. The spectral width across all centre wavelengths is sufficient for sub-10 fs pulses. We routinely achieve pulse lengths between 10 and 20 fs. The system has stably run without any adjustments for three months.

To scrutinize the characteristics of the pump laser/NOPA combination, we developed a detector capable of shot-to-shot measurements at a rep rate of 200 kHz. This detector was employed to analyse the shot-to-shot fluctuations and correlation of the NOPA at various repetition rates and pulse picker settings of the pump laser. Beyond the overall rms of the output pulses all relevant nonlinearly generated pulses inside the NOPA were compared and correlated to the pump laser behaviour. It was found that the long-term fluctuations of the NOPA output are below 0.5% at a 0.1% level of the pump laser.

Q 47: Open Quantum Systems

Time: Thursday 11:00–13:00 Location: HS 3219

Q 47.1 Thu 11:00 HS 3219

Optimal Cooling in Markovian Quantum Systems — •Emanuel Malvetti — School of Natural Sciences, Technische Universität München, 85737 Garching, Germany — Munich Center for Quantum Science and Technology & Munich Quantum Valley, 80799 München, Germany

We address the task of cooling a Markovian quantum system to a pure state. Here the system drift takes the form of a Lindblad master equation and we assume fast control over the unitary group. This setting allows for a natural reduction of the control system to the eigenvalues of the state density matrix. We give a simple necessary and sufficient characterization of systems which are (asymptotically) coolable, and present explicit time-optimal cooling protocols for chosen low-dimensional systems. As an outlook we connect the task of cooling subsystems to embedding non-Markovian dynamics using a Markovian shell.

Q 47.2 Thu 11:15 HS 3219

Quantum speed limit for perturbed open systems — •Benjamin Yadin, Satoya Imai, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

Quantum speed limits provide upper bounds on the rate with which a quantum system can move away from its initial state. Here, we provide a different kind of speed limit, describing the divergence of a perturbed open system from its unperturbed trajectory. In the case of weak coupling, we show that the divergence speed is bounded by the quantum Fisher information under a perturbing Hamiltonian, up to an error which can be estimated from system and bath timescales. We give two applications of our speed limit. Firstly, it enables experimental estimation of quantum Fisher information in the presence of decoherence that is not fully characterised. Secondly, it implies that large quantum work fluctuations are necessary for a thermal system to be driven quickly out of equilibrium under a quench.

Q 47.3 Thu 11:30 HS 3219

Adiabatic quantum trajectories in engineered reservoirs — •Emma King[1], Luigi Giannelli[2,3,4], Raphaël Menu[1], Johannes Kriel[5], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Dipartimento di Fisica e Astronomia “Ettore Majorana”, Università di Catania, Via S. Sofia 64, 95123 Catania, Italy — [3]CNR-IMM, UoS Università, 95123 Catania, Italy — [4]INFN Sezione di Catania, 95123 Catania, Italy — [5]Institute of Theoretical Physics, Stellenbosch University, Stellenbosch 7600, South Africa

We analyze the efficiency of protocols for adiabatic quantum state transfer assisted by an engineered reservoir. The target dynamics is a quantum trajectory in the Hilbert space and is the fixed point of a time-dependent master equation. We specialize to quantum state transfer in a qubit and determine the optimal schedule for a class of time-dependent Lindblad equations. The speed limit on state transfer is extracted from a physical model of a qubit coupled to a reservoir, from which the Lindblad equation is derived in the Born-Markov limit. Our analysis shows that the resulting efficiency is comparable to the efficiency of the optimal unitary dynamics. Numerical studies indicate that reservoir-engineered protocols could outperform unitary protocols outside the regime of the Born-Markov master equation, namely, when correlations between the qubit and reservoir become relevant. Our study contributes to the theory of shortcuts to adiabaticity for open quantum systems and to the toolbox of protocols of the NISQ era.

Q 47.4 Thu 11:45 HS 3219

Stochastic unravelling of Lindblad equation for N coupled oscillators — Juan Moreno[1], •Abhijit Pendse[1], and Alexander Eisfeld[1,2] — [1]Max Planck Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Universität Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany

The dynamics of a system of N coupled oscillators in presence of gain/loss can be understood by solving the Lindblad master equation numerically. However, the time propagation of the density matrix presents limitations in the computational memory since its size increases exponentially with the number of oscillators N. In this talk, we will present an alternative way to study the dynamics of this system using the quantum state diffusion formalism (QSD). In this formalism, the dynamics of the density matrix is given by a mean over an ensemble of trajectories that are obtained by propagating a stochastic QSD equation. This stochastic equation is written in terms of a non-Hermitian Hamiltonian, whose diagonalization leads to QSD equation that is only coupled via noise correlations. This allows one to do time propagation of N individual oscillators without dealing with the memory limitations that are present in the numerical solution of the Lindblad equation.

Q 47.5 Thu 12:00 HS 3219

Collision models from the perspective of fast scattering events — •Michael Gaida and Stefan Nimmrichter — Universität Siegen, Deutschland

A collision model is a blueprint for generic opensystems in which the environment is modeled as a sequence of ancillas unitarily interacting with the system. It can be viewed as a mathematical idealization of scattering processes in which kinetics are reduced to a mere swichting on and off of the interaction. Such models are capable of describing thermalization processes if one restricts to energy preserving interaction terms, but the link to dynamical scattering models with both internal and motional degrees of freedom remains to be explored. Recently this link has been investigated in a one-dimensional setting [1, 2]. Here we consider two and three-dimensional scenarios and study under which conditions they can be described by collision models, once the motional degrees of freedom are averaged out. Specifically, we focus on (non-relativistic) high energy scattering and the energy exchange between internal and kinetic energy. We identify the parameter regimes and interaction types that lead to Gibbsian or non-Gibbsian equilibrium state of the internal degrees of freedom.

[1] S. L. Jacob, M. Esposito, J. M. R. Parrondo, and F. Barra, Quantum scattering as a work source, Quantum 6, 750 (2022).

[2] S. L. Jacob, M. Esposito, J. M. Parrondo, and F. Barra, Thermalization induced by quantum scattering, PRX Quantum 2, 020312 (2021).

Q 47.6 Thu 12:15 HS 3219

Spin Coherence in Strongly-Coupled Spin Baths in Quasi Two-Dimensional Layers — Philip Schätzle[1,2] and •Walter Hahn[1] — [1]Fraunhofer Institute for Applied Solid State Physics IAF, Tullastr. 72, 79108 Freiburg, Germany — [2]Department of Sustainable Systems Engineering (INATECH), University of Freiburg, Emmy-Noether-Str. 2, 79110 Freiburg, Germany

We investigate the spin-coherence decay of NV^--spins interacting with the strongly-coupled disordered bath of the substitutional nitrogen defects in diamond layers. We show that the short-time decay follows a stretched-exponential function with a dimensionality-dependent stretched-exponential parameter that challenges analytical predictions. We find that this discrepancy is caused by the hyperfine interaction which strongly modifies the bath dynamics. We use a novel method based on the correlated-cluster expansion applied to partitions of the bath, which includes important high-order spin correlations. The results pave the way for enhanced materials for quantum-technology devices.

Q 47.7 Thu 12:30 HS 3219

Dissipative quantum phase transition in an interacting many-particle system: from two-level to multilevel spins — •Lukas Pausch, François Damanet, Thierry Bastin, and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, Belgium

The dissipative Lipkin-Meshkov-Glick model of N all-to-all interacting two-level systems subject to collective and/or individual decay is known to display a dissipative phase transition. There, the collective or individual nature of the dissipation defines the order of the phase transition and the characteristics of the different phases, while having no impact on the position of the critical point.

Here, we investigate a generalization of this model to d-level spins ($d \geq 2$). While basic features of the transition, such as the critical point, remain identical to the two-level case, the spin expectation values that characterize the different phases become ever more distinct from each other as d increases. Furthermore, depending on the exact form of the dissipator, the critical point transforms into a critical region that grows with d. Around the phase transition, the steady state of the system is entangled, and different choices of the dissipator may lead to a suppression or even an enhancement of entanglement by the individual dissipation.

Q 47.8 Thu 12:45 HS 3219

Exceptional points at x-ray wavelengths — •Fabian Richter and Adriana Pálffy — Julius-Maximilians-Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Non-Hermitian Hamiltonians allow for an effective description of dissipative systems. They exhibit a variety of exciting phenomena that cannot be observed in the Hermitian realm. Exceptional Points (EPs) are a prime example thereof. At EPs not only the complex eigenvalues, but also the eigenvectors coalesce and sensitivity to perturbations is enhanced. This concept has recently found fertile ground in optics and photonics where non-Hermitian eigenstates can be created and superposed through optical gain and loss [1]. So far, these concepts have been mostly discussed in the optical regime. Similar control of x-rays is desirable due to their superior penetration power, high focusability and detection efficiency.

Here, we investigate theoretically non-Hermitian x-ray photonics in a thin-film cavity setup containing Mössbauer nuclei resonant to the x-ray radiation entering under grazing incidence. These cavities present loss that can be controlled via adjustment of the cavity geometry and the x-ray incidence angle [2]. We show that external magnetic fields may be used to tune the system towards EPs and explore the rich topological properties of the x-ray thin-film nanostructures.

[1] L. Feng *et al.*, Nature Photon. **11**, 752-762 (2017).
[2] X. Kong, D. Chang, A. Pálffy , Phys. Rev. A **102**, 033710 (2020).

Q 48: Ultra-cold Atoms, Ions and BEC III (joint session A/Q)

Time: Thursday 14:30–16:30 Location: HS 1010

Q 48.1 Thu 14:30 HS 1010

ATOMIQ: An easy-to-use abstarction layer for ARTIQ — •Suthep Pomjaksilp[1], Christian Hölzel[2], Florian Meinert[2], Herwig Ott[1], and Thomas Niederprüm[1] — [1]Department of Physics and research center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Kaiserslautern, Germany — [2]5th Institute of Physics, Universität Stuttgart, Stuttgart, Germany

In recent years, the emergence of a vast landscape of quantum technology experiments created a still growing demand for high perfomance experiment control systems. In contrast to proprietary systems, the Sinara hardware and ARTIQ software ecosystem are fully open-source while reaching nanosecond timing performance. Yet, the subset of Python commands used by ARTIQ predominantly describes hardware like digital frequency synthesizers, DACs and ADCs, making it time-consuming to implement experimental sequences.

The ATOMIQ framework aims to bridge the gap between this hardware and entities familiar to experimental physicists like AOM controlled lasers, coils and cameras. In addition, ATOMIQ consolidates common routines (loading a magneto-optical trap, load and evaporate a dipole trap) into building blocks which can be transported in between experiments while preserving the possibility to leverage the high-perfomance primitives of ARTIQ. Finally, we demonstrate how ATOMIQ can be seamlessly integrated into a non-realtime data acquisition and control system.

Q 48.2 Thu 14:45 HS 1010

Circular Rydberg qubits of alkaline earth atoms in optical tweezers — •Einius Pultinevicius, Christian Hölzl, Aaron Götzelmann, Moritz Wirth, and Florian Meinert — 5th Institute of Physics, Universität Stuttgart, Stuttgart, Germany

We report the first demonstration of trapped circular Rydberg states of an alkaline-earth metal atom (Strontium) in an optical tweezer array. Circular Rydberg states promise orders of magnitude longer lifetimes compared to their low-L counterparts, which allows for overcoming fundamental limitations in the coherence properties of Rydberg atom based quantum simulators and quantum computers. In our experiments, we utilize tweezer trapped Strontium atoms and demonstrate efficient transfer into high-n circular Rydberg atoms with n=79 via rapid adiabatic passage. We implement a qubit between circular states of closeby hydrogenic manifolds coupled via a two-photon microwave transition and study its coherence via Rabi and Ramsey measurements. We also demonstrate trapping of the circular state enabled via the second available valence electron of the Sr atom. Our results open exciting prospects for exploiting unique properties of long-lived circular states of two-valence electron atoms, comprising coherent core excitation, for quantum technologies.

Q 48.3 Thu 15:00 HS 1010

Universal Self-Organization Dynamics in a Strongly Interacting Fermi Gas — •Timo Zwettler[1,2], Tabea Bühler[1,2], Aurélien Fabre[1,2], Gaia Bolognini[1,2], Victor Helson[1,2], Giulia del Pace[1,2], and Jean-Philippe Brantut[1,2] — [1]Institute of Physics, EPFL, Switzerland — [2]Center of Quantum Science and Engineering, EPFL, Lausanne, Switzerland

Cavity-coupled many-body systems constitute a new emergent field in condensed matter systems, where complex quantum materials are combined with cavity quantum electrodynamics (cQED) to substantially modify material properties by strong light-matter coupling.

We realize a prototypical cavity quantum material by combining cQED with a strongly interacting Fermi gas, providing an ideal, microscopically controllable platform for the study of collective light-matter coupling in strongly correlated matter. We explore the interplay of strong, short-range collisional interactions in the Bose-Einstein condensate to Bardeen-Cooper-Schrieffer (BEC-BCS) crossover and engineered, long-range cavity-mediated interactions, which arise from a two-photon scattering process in the transversally pumped atom-cavity system.

In recent experiments, we advance our understanding of density-wave ordering by investigating the out-of-equilibrium dynamics following a quench across the quantum phase transition. By observing the photons leaking from the optical cavity, we reveal the universal behaviour of the order parameter dynamics in this driven-dissipative system.

Q 48.4 Thu 15:15 HS 1010

Repulsively-bound pair states in the 1D extended Hubbard model — •Pascal Weckesser[1,2], Kritsana Srakaew[1,2], David Wei[1,2], Daniel Adler[1,2], Suchita Agrawal[1,2], Immanuel Bloch[1,2,3], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany

The binding between two particles is usually mediated by attractive forces. Operating in an external confinement however, one can observe pair-binding despite having repulsive interactions. The existence of such bound states has been conjectured for the one-dimensional extended Hubbard model, yet so far their observation remained elusive.

In this talk, we present our recent findings on realizing one-dimensional extended Hubbard systems for ^{87}Rb atoms trapped in optical lattices and explore the emerging exotic bound states. Here, the long-range repulsion between two adjacent lattices sites is engineered using stroboscopic Rydberg dressing. We probe the presence of the bound state by monitoring the out-of-equilibrium dynamics of two particles using our quantum gas microscope, giving us direct access to the evolution of the density and the underlying correlations. As a final measurement, we explore multiparticle binding between three atoms. Our results path the way to study complex extended Hubbard models and string breaking in spin chains.

Q 48.5 Thu 15:30 HS 1010

Josephson effect in a double-well potential and its generalization for finite temperatures — •Kateryna Korshynska[1,2] and Sebastian Ulbricht[2,3] — [1]Department of Physics, Taras Shevchenko National University of Kyiv, 64/13, Volodymyrska Street, Kyiv 01601, Ukraine — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, D-38116 Braunschweig, Germany — [3]Technische Universität Braunschweig, D-38106 Braunschweig, Germany

In modern cold atom physics the study of many-particle bosonic systems gives insight into fundamental quantum processes and lays the foundation for powerful tools in precision metrology. The quantum nature of a bosonic system manifests itself in the Josephson effect, when the particles are placed in a double-well potential. In this potential one can define time-dependent probabilities of a single particle to be in the left or the right well. From that we develop the description of a many-particle system in the regime of global coherence (BEC) and in the case when the system is partially non-coherent. Focusing on the latter case we address the changes in many-particle dynamics, giving rise to a generalization of Josephson equations, which describe the system in non-equilibrium at finite temperatures. In this regime they predict deviations from the standard Josephson effect, which become more pronounced for high temperatures and a small number of bosons. For low temperatures, moreover, we find that the amplitude of Josephson oscillations is restricted. This prediction can be used to test the principles of statistics of a many-particle quantum system.

Q 48.6 Thu 15:45 HS 1010

Investigating interference with phononic bright and dark states in a trapped ion — •Robin Thomm[1], Harry Parke[1], Alan C. Santos[2], André Cidrim[2], Gerard Higgins[1], Marion Mallweger[1], Natalia Kuk[1], Shalina Salim[1], Romain Bachelard[2,3], Celso J. Villas-Boas[2], and Markus Hennrich[1] — [1]Department of Physics, Stockholm University, Stockholm, Sweden — [2]Departamento de Física, Universidade Federal de São Carlos, São Carlos, Brazil — [3]Institut de Physique de Nice, Université Côte d'Azur, Valbonne, France

Interference underpins some of the most unusual and impactful properties of both the classical and quantum worlds, from macroscopic systems down to the level of single photons. In this work a new description of interference, based on the formation of collective bright and dark states, is investigated experimentally. We employ a single trapped ion, whose electronic states are coupled to two of its motional modes in order to simulate a multi-mode light-matter interaction. We observe the emergence of phononic bright and dark states for both a single phonon and a superposition of coherent states. The collective dynamics of these systems demonstrate that a description of interference based solely on bright and dark states is sufficient to explain the light-matter coupling of any initial state in both the quantum and classical regimes.

Q 48.7 Thu 16:00 HS 1010

Fermi-liquid-like thermal and spin diffusion between unitary superfluids by dissipation — •Meng-Zi Huang, Philipp Fabritius, Jeffrey Mohan, Mohsen Talebi, Simon Wili, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Dissipation engineering in strongly correlated systems is an emerging territory of nontrivial interplay between coherent and incoherent dynamics. With direct particle and entropy measurements in a two-terminal setting, we show that the Seebeck response of a strongly-interacting Fermi gas can be enhanced by particle dissipation. This enhancement is robust when changing the dimensionality of the connection between the reservoirs and even the nature of the dissipation mechanisms, namely from spin-selective to pairwise losses. The dissipation also enhances thermal diffusion and spin diffusion, restoring the Fermi-liquid thermal and spin conductance which is initially strongly suppressed in this non-Fermi liquid. Although a microscopic theory is still missing, we provide a phenomenological model that can describe the observations.

Q 48.8 Thu 16:15 HS 1010

A Fermionic Quantum Gas Microscope for the Continuum — •Joris Verstraten, Maxime Dixmerias, Kunlun Dai, Shuwei Jin, Bruno Peaudecerf, Tim de Jongh, and Tarik Yefsah — Ultracold Fermi Gases, Laboratoire Kastler Brossel, Paris, France

Quantum gas microscopes have emerged as powerful tools to investigate the microscopic details of ultracold many-body systems. It enables the imaging of dilute quantum gases with single atom resolution and has shed light on the properties of various systems such as the Bose- and Fermi-Hubbard models. As it relies on optical lattice potentials, this method was restricted to periodic systems, in which atoms are already constrained to move between lattice sites. On the other hand, using a deep optical lattice to pin atoms initially prepared in a continuous trap leads to a non-trivial projection on discrete positions.

Here we report on the realization of a Lithium 6 based quantum gas microscope intended to study the microscopic characteristics of ultracold Fermi gases inside the continuum regime. We investigate the fidelity of the pinning process through a dynamical study of individually prepared non-interacting atoms in free space, and are able to experimentally reconstruct the wavefunction of single atoms expanding from a locally harmonic trap. Imaging fidelity as high as 99% can also be achieved under the right experimental conditions, proving that single-atom imaging of bulk systems is not only technically possible but also a reliable method of measuring the microscopic properties of continuous sytems. This opens up the path for the study of correlations in continuous, strongly interacting systems of fermions.

Q 49: Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)

Time: Thursday 14:30–16:15 Location: HS 1098

Q 49.1 Thu 14:30 HS 1098

Laser-spectroscopic determination of the nuclear charge radius of ^{13}C — •Patrick Müller[1], Emily Burbach[1], Phillip Imgram[2], Kristian König[1], Wilfried Nörtershäuser[1], and Julien Spahn[1] — [1]Institut für Kernphysik, TU Darmstadt, 64289 Darmstadt, Germany — [2]Instituut voor Kern- en Stralingsfysica, KU Leuven, 3001 Leuven, Belgium

Collinear laser spectroscopy (CLS) has proven to be a powerful method to benchmark nuclear and atomic structure calculations. Light heliumlike systems are ideal test cases for both worlds as they exhibit a greatly varying nuclear structure and are accessible for high-precision ab-initio calculations. In an ongoing effort, it is planned to determine absolute and differential nuclear charge radii, R_C and $\delta\langle r^2\rangle$, of the light elements Be to N by purely using CLS and ab-initio nonrelativistic quantum electrodynamics calculations in the helium-like ions. As a first step, the $1s2s\,^3\mathrm{S}_1 \rightarrow 1s2p\,^3\mathrm{P}_J$ transitions in $^{12,13}\mathrm{C}^{4+}$ were determined using the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA) at the Technical University of Darmstadt. We present results for $\delta\langle r^2\rangle^{12,13}$ and the hyperfine structure of $^{13}\mathrm{C}^{4+}$, which is modulated by significant hyperfine-induced mixing, and compare them to ab-initio nuclear and atomic structure calculations. In both cases, our model independent results can be used to improve theory and help quantifying theoretical uncertainties. A comparison to the model-dependent results from elastic electron scattering and muonic atom spectroscopy will help to improve these experimental methods. This project is supported by DFG (Project-ID 279384907 - SFB 1245).

Q 49.2 Thu 14:45 HS 1098

Coherent excitation of a Sub-mHz optical magnetic quadrupole transition — •Valentin Klüsener[1,2], Sebstian Pucher[1,2], Dimitry Yankelev[1,2], Felix Spriestersbach[1,2], Jan Trautmann[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Ultranarrow clock transitions to metastable states are fundamental for many applications in quantum metrology, simulation and information. We report on the first coherent excitation of the $^1\mathrm{S}_0$-$^3\mathrm{P}_2$ magnetic quadrupole (M2) transition in ^{88}Sr. By confining atoms in a state insensitive three-dimensional optical lattice, we achieve excitation fractions of 97 % and observe Fourier limited linewidths as narrow as 55 Hz. We characterize the coherence of the prepared states by performing Ramsey spectroscopy and find coherence times of 10 ms, which can be extended to 250 ms with a spin-echo sequence. Finally, we use our spectroscopic results to determine the decay rate of the M2 transition to $154(32)\times10^{-6}\,\mathrm{s}^{-1}$ in agreement with longstanding theoretical predictions. These results establish an additional clock transition in neutral strontium and pave the way for applications of the metastable $^3P_2$ state in precision quantum metrology, simulation and information processing.

Q 49.3 Thu 15:00 HS 1098

Multi-Cubic-Meter Atom Trapping for Project 8 — •Alec Lindman for the Project 8-Collaboration — Institute for Physics and Excellence Cluster PRISMA+, Johannes Gutenberg University Mainz

The Project 8 direct neutrino mass experiment will achieve its next-generation sensitivity of 40 meV by improving precision (with its Cyclotron Radiation Emission Spectroscopy method), statistics (which scale with active volume in Project 8 rather than area), and control of systematics (by replacing molecular tritium with atomic tritium).

Since atomic tritium recombines on contact with surfaces, a large, static magneto-gravitational trap will hold the tritium atoms in free space. To achieve its sensitivity, Project 8 requires a density of about 10^{17} atoms per m^3 at about 1 mK and a total volume of about 100 m^3, divided among ten identical 10 m^3 traps.

Keeping such a trap full over the multi-year runtime of the experiment requires producing a high flux of atoms (10^{19} atoms/s) with a hot atom source, continuously cooling them (first on surfaces, and then using magnetic fields and gas-gas collisions), and finally injecting the cold beam into the trap. This talk will describe the intended trap design, the difficulties and advantages of a large trap, plans for the cooling system, and experimental progress on a high-flux tritium-compatible atom source.

Q 49.4 Thu 15:15 HS 1098

Sensitivity of Project 8's wire detector for an atomic tritium beam — •Darius Fenner and Martin Fertl — Institut für Physik, Johannes Gutenberg-Universität Mainz, Mainz, Deutschland

The Project 8 experiment aims to achieve a sensitivity of 40 meV on the neutrino mass through precise measurements of the tritium beta spectrum near its endpoint. To achieve the required energy resolution, the production of atomic tritium is imperative because it has no molecular final state distribution. Such a distribution, caused by vibrational and rotational modes of the molecules, smears the energy spectrum. At the setup in Mainz the thermal dissociation of hydrogen instead of tritium is studied. The efficiency of this process is quantified using a wire detector equipped with three 5μm tungsten wires. As atomic hydrogen recombines on the wire surface and releases the recombination energy, the temperature change of the wire is measured as a resistance change. However, the measured signal depends on the position along the wire, as heat can more readily dissipate near the mountings. In this work, the wire's sensitivity curve is determined as a function of wire position. The measurement process involves a 2D scan of the wire while performing pointwise heating with a laser. Moreover, the sensitivity is simulated in a COMSOL heat transfer simulation to complement the experimental findings.

Q 49.5 Thu 15:30 HS 1098

Using Non-linear Dissociation Processes of BeH+ for the Alignment of the Laser Pulse Overlap in XUV Frequency Comb Spectroscopy of He+ — •Florian Egli, Jorge Moreno, Theodor Wolfgang Hänsch, Thomas Udem, and Akira Ozawa — Max-Planck-Institut für Quantenoptik, Garching, Deutschland

The energy levels of hydrogen-like atoms and ions are accurately described by bound-state quantum electrodynamics (QED). With spectroscopic measurements of hydrogen and hydrogen-like atoms, the Rydberg constant and the proton charge radius can be determined. The comparison of the physical constants obtained from different combinations of measurements serves as a consistency check for the theory. The hydrogen-like He^+ ion is an interesting spectroscopic target for QED tests. Due to their charge, He^+ ions can be held nearly motionless in the field-free environment of a Paul trap, providing ideal conditions for high-precision measurements. The 1S-2S two-photon transition in He^+ can be directly excited by an extreme-ultraviolet frequency comb at 60.8 nm generated by a high-power infrared frequency comb using high-order harmonic generation (HHG). In order to perform Doppler-free spectroscopy on the 1S-2S transition, the frequency comb is split into double pulses which are overlapped at the ions. As a signal for the pulse overlap alignment, we investigate non-linear dissociation processes of BeH^+. The processes discussed here are using 204 nm and 255 nm light, which can be generated from our infrared frequency comb.

Q 49.6 Thu 15:45 HS 1098

An optical clock for robust operation and remote comparisons — •Saaswath JK, Martin Steinel, Melina Filzinger, Jian Jiang, Ekkehard Peik, Nils Huntemann, and the Opticlock consortium — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

We report on a transportable and easy-to-operate optical clock that uses the $^2S_{1/2} - ^2D_{3/2}$ transition of a single trapped $^{171}Yb^+$ ion at 436 nm as the reference. The system has been developed within a pilot project for quantum technology in Germany led by industry and is set up in two 19" racks [1]. In this way, transportation can easily be realized, and the large degree of automatization allows for robust operation. Comparisons to existing high-accuracy optical clock systems at PTB enabled verification of the clock's uncertainty budget at the low 10^{-17} level. During these tests, operation with 99.8% availability over more than 14 days has been achieved. Furthermore, the system has been operated for a significant fraction of the year 2023, enabling a very accurate determination of its frequency and contributions to timescales. We are currently improving the robustness of the setup and reducing uncertainties of shifts from thermal radiation and electric field gradients. This prepares Opticlock well for transportation to Finnland and Czechia, where it will be compared to other high-performance optical clocks. This will demonstrate a novel approach for key comparisons in time and frequency.

[1] J. Stuhler, et al. Measurement: Sensors 18, 100264 (2021)

Q 49.7 Thu 16:00 HS 1098

Laser spectroscopy of Fermium-255 at the RISIKO mass separator facility — •Matou Stemmler for the Fermium-Collaboration — Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany

Laser spectroscopy can provide information about fundamental properties of both atomic and nuclear structure. Such measurements are of particular importance for the heaviest actinides and superheavy elements, where data is sparse. During the last measurement campaign at the RISIKO mass separator facility in the Institute of Physics at Johannes Gutenberg University Mainz (JGU), nine successive samples of the artificially produced ultra-rare isotope ^{255}Fm (Z=100) of 10^8 to 10^9 atoms each, were used to study the atomic and nuclear structure of fermium. The samples originate from an initial ^{254}Es sample that was produced at the Oak Ridge National Laboratory high flux nuclear reactor (USA). The sample was subsequently re-irradiated at the Institut Laue-Langevin reactor in Grenoble (F) with thermal neutrons to produce ^{255}Es (half-life: 39.8 d), which decays to ^{255}Fm (20.07 h) via β^- decay. This presentation will focus on the atomic structure studies of ^{255}Fm, for which a new three-step laser ionization scheme was developed. Rydberg convergences were studied and the accuracy of the ionization potential was improved [1].

[1] J. Am. Chem. Soc. 44, 14609-14613 (2018)

Q 50: Quantum Gases (joint session Q/A)

Time: Thursday 14:30–16:30 Location: Aula

Q 50.1 Thu 14:30 Aula

Braiding Laughlin quasi-holes in ultracold atoms using Ramsey interferometry — •Felix Palm[1,2], Nader Mostaan[1,2], Nathan Goldman[2], and Fabian Grusdt[1] — [1]LMU Munich & MC-QST, Munich, Germany — [2]CENOLI, Université Libre de Bruxelles, Brussels, Belgium

Braiding non-Abelian anyons in topologically ordered systems has been proposed as a possible route towards topologically protected quantum computing. While recent experiments based on various platforms have made significant progress towards this goal, coherent control over individual anyonic excitations has still not been achieved today. At the same time, progress in cold-atom quantum simulators resulted in the realization of a two-boson $\nu = 1/2$-Laughlin state, a paradigmatic fractional quantum Hall state hosting Abelian anyonic quasi-holes.

Here we show that cold atoms in quantum gas microscopes are a suitable platform to create and manipulate these quasi-holes. First, we show that a Laughlin state of eight bosons can be realized by connecting small patches accessible in experiments. Next, we demonstrate that two cross-shaped pinning potentials are sufficient to create two quasi-holes in this Laughlin state. Starting with these two quasi-holes we numerically perform an adiabatic exchange procedure, and reveal their semionic braiding statistics for various exchange paths, thus clarifying the topological nature of these excitations. Finally, we propose an experimentally feasible interferometry protocol to probe the braiding phase in quantum gas microscopes, using a two-level impurity immersed in the fractional quantum Hall fluid.

Q 50.2 Thu 14:45 Aula

Adiabatic Preparation of a Chiral Spin Liquid — •Moritz Schlechtriem, Francesco Petiziol, and André Eckardt — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstraße 36, 10623 Berlin, Germany

Efficient protocols to prepare spin-liquid states are essential for exploring these phases of matter and harnessing their potential for applications. The goal of this study is to investigate the adiabatic preparation of a chiral spin liquid ground state on the Kagome lattice. Considering different easily-realizable initial Hamiltonians and different system sizes, the minimal duration for a high-fidelity adiabatic transition into the spin-liquid phase is determined and optimal adiabatic paths are explored. In a second step, the analysis is extended to the case in which the spin-liquid Hamiltonian is realized via Floquet engineering.

Q 50.3 Thu 15:00 Aula

The anyon-Hubbard model: From few to many-body — •Martin Bonkhoff — I. Institut für Theoretische Physik, Universität Hamburg

Recent experimental progress in the engineering of density-dependent Peierls phases has rekindled the interest in one-dimensional anyonic lattice models of the Hubbard type. We review specific ground-state properties of such anyons on hand of the single-species anyon-Hubbard model. Thereby we focus primarily on the distinction between few-particle systems, or very small system sizes, and a real many-body setting [2,3]. For the former case we use integrable techniques to study the properties of the model, which is contrasted then with field-theoretical methods for long-wavelengths. The emphasis is thereby on the coherence properties of the model that are intrigiungly modified by the statistical interactions in contrast to ordinary, local inter-particle interactions. We find a quite different phenomenology for the two regimes and discuss related experimental challenges.

[1] Martin Bonkhoff, Simon B. Jäger, Imke Schneider, Axel Pelster, and Sebastian Eggert, Phys. Rev. B 108, 155134 (2023)

[2] Martin Bonkhoff, Kevin Jägering, Sebastian Eggert, Axel Pelster, Michael Thorwart, and Thore Posske, Phys. Rev. Lett. 126, 163201 (2021)

Q 50.4 Thu 15:15 Aula

Bogoliubov theory of 1D anyons in a lattice — •Binhan Tang[1], Axel Pelster[1], and Martin Bonkhoff[2] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]I. Institute for Theoretical Physics, Universität Hamburg, Germany

In a one-dimensional lattice anyons can be defined via generalized commutation relations containing a statistical parameter, which interpolates between the boson limit and the pseudo-fermion limit. The corresponding anyon-Hubbard model is mapped to a Bose-Hubbard model via a fractional Jordan-Wigner transformation, yielding a complex hopping term with a density-dependent Peierls phase. Here we work out a corresponding Bogoliubov theory. To this end we start with the underlying mean-field theory, where we allow for the condensate a finite momentum and determine it from extremizing the mean-field energy. With this we calculate various physical properties and discuss their dependence on the statistical parameter and the lattice size. Among them are both the condensate and the superfluid density as well as the equation of state and the compressibility. Based on the mean-field theory we then analyse the resulting dispersion of the Bogoliubov quasi-particles, which turns out to be in accordance with the Goldstone theorem. In particular, this leads to two different sound velocities for wave propagations to the left and the right, which originates from parity breaking.

Q 50.5 Thu 15:30 Aula

Hamiltonian learning for quantum field theories — Robert Ott[1,2], Torsten Zache[1,2], •Maximilian Prüfer[3], Sebastian Erne[3], Mohammadamin Tajik[3], Hannes Pichler[1,2], Jörg Schmiedmayer[3], and Peter Zoller[1,2] — [1]Institute for Theoretical Physics, University of Innsbruck — [2]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences — [3]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien

Synthetic quantum systems, such as those based on bosonic quantum gases, offer an excellent opportunity to study complex phenomena arising in quantum many-body physics. Recently, a set of efficient tools called Hamiltonian learning (HL) has been developed to uncover the underlying microscopic interactions in quantum systems from experiments. While HL is well developed for discrete lattice-based many-body systems, its application to continuous quantum systems faces a challenge due to the absence of a lattice scale. In this work, we propose a protocol that capitalizes on the locality of effective field theories to extract their Hamiltonians from experimental data. By varying the resolution scale of the measurements, our protocol gives access to the scale dependence of coupling parameters reminiscent of the running of couplings with the renormalization group flow. To demonstrate the effectiveness of our method, we apply it to theoretical studies of both classical and quantum fields. We furthermore showcase its application in an ultracold quantum gas experiment, learning the Hamiltonian underlying its classical statistical description.

Q 50.6 Thu 15:45 Aula

Towards simulation of lattice gauge theories with ultracold ytterbium atoms in hybrid optical potentials — •Rene Villela[1,2], Tim Höhn[1,2], Etienne Staub[1,2], Leonardo Bezzo[1,2], Ronen Kroeze[1,2], and Monika Aidelsburger[1,2,3] — [1]Ludwig-Maximilians-Universität, München, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Gauge theories play a fundamental role in our understanding of nature, ranging from high-energy to condensed matter physics. Their formulation on a regularized periodic lattice geometry, so-called lattice gauge theories (LGTs), has proven invaluable for theoretical studies, as numerical studies on, e.g., their real-time dynamics are computationally challenging. We report progress on developing a quantum simulator for LGTs using neutral ytterbium atoms. Ytterbium's internal level structure provides a ground and metastable clock state pair, and fermionic isotopes further host nuclear spin degrees of freedom. We combine optical lattice and optical tweezers technology that can enable robust and scalable implementation of LGTs. To realize state-selective control, which is key for our approach to simulate LGTs, we exploit magic and tune-out wavelengths. We present the first measurements of such wavelengths near the narrow cooling transition at 556 nm and discuss prospects in implementing local gauge invariance.

Q 50.7 Thu 16:00 Aula

Fast preparation of cold Ytterbium gases for Rydberg quantum optics experiments — •Xin Wang, Thilina Muthuarachchige, Tangi Legrand, Ludwig Müller, Wolfgang Alt, Eduardo Uruñuela, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons. Demonstrations of photon-photon gates or multi-photon bound states based on this concept have so far exclusively employed ultracold alkali atoms. Two-valence electron species, such as Ytterbium, offer unique novel features namely narrow-linewidth laser-cooling, optical detection and ionization or long-lived nuclear-spin memory states.

In this talk, we present our experimental progress towards the realization of strong photon-photon interactions, mediated by the Yb-174 Rydberg polaritons formed in a 1-D ultracold Ytterbium gas. Specifically, we discuss our compact two-chamber experimental design enabling fast production of ultracold Yb-174 gases at high density. Instead of an oven and Zeeman slower, we use a fast-loading two-stage hybrid MOT sequence to prepare and load the atoms in an elongated dipole trap, where we generate Rydberg polaritons under Rydberg electromagnetically induced transparency. Owing to the zero nuclei spin of Yb-174 and singlet spin state in bivalent structure, longer coherent times are expected compared to experiments with alkali atoms.

Q 50.8 Thu 16:15 Aula

Borromean states in a one-dimensional three-body system — •Tobias Schnurrenberger[1], Lucas Happ[2], and Maxim Efremov[1] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, 89081, Ulm, Germany — [2]Few-body Systems in Physics Laboratory, RIKEN Nishina Center for Accelerator-Based Science, Wako, Saitama 351-0198, Japan

We show the existence of Borromean states in a one-dimensional quantum three-body system composed of two identical, heavy bosons and a different, lighter particle. It is assumed that there is no interaction between the two bosons, while the heavy-light subsystems do not have a bound state. Within the framework of the Faddeev equations, the three-body spectrum and the corresponding wave-functions are computed numerically. In addition, we identify the parameter-space region of the heavy-light interaction, where the Borromean states occur, investigate their dependence on the mass ratio, and evaluate their geometric properties.

Q 51: Quantum Optical Correlations

Time: Thursday 14:30–16:30 Location: HS 1199

Invited Talk Q 51.1 Thu 14:30 HS 1199

From the origin of antibunching to novel quantum light sources based on two-photon interference — •Martin Cordier, Luke Masters, Gabriele Maron, Xin-Xin Hu, Lucas Pache, Philipp Schneeweiss, Max Schemmer, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Generating useful quantum states of light is key to many applications in quantum science and technology. Here, I will report on a new approach to controlling and tailoring the photon statistics of light fields. It is based on an effect, which we put into evidence in a recent experiment and which challenges the conventional notion that a single two-level emitter can only scatter one photon at a time [1]. There, we show that photon antibunching in resonance fluorescence arises from the destructive interference between two types of two-photon scattering processes, referred to as coherent and incoherent scattering. Building on this insight, we also study the collective enhancement of this incoherently scattered two-photon component when laser light propagates through an atomic ensemble. By adjusting the number of atoms and the laser detuning, we have full control over the two-photon interference, which allows us to tune the photon statistics of the transmitted light from strong photon bunching to antibunching [2,3].

[1] Masters et al., Nature Photonics 17, 972 (2023). [2] Prasad et al., Nature Photonics 1 (2020). [3] Cordier et al., Phys. Rev. Lett. 131, 183601 (2023).

Q 51.2 Thu 15:00 HS 1199

Boson bunching is not maximized by indistinguishable particles — •Benoît Seron[1], Leonardo Novo[1,2], and Nicolas J. Cerf[1] — [1]Centre for Quantum Information and Communication, Brussels, Belgium — [2]International Iberian Nanotechnology Laboratory (INL), Braga, Portugal

Boson bunching is amongst the most remarkable features of quantum physics. A celebrated example in optics is the Hong-Ou-Mandel effect, where the bunching of two photons arises from a destructive quantum interference between the trajectories where they both either cross a beam splitter or are reflected. This effect takes its roots in the indistinguishability of identical photons. Hence, it is generally admitted – and experimentally verified – that bunching vanishes as soon as photons can be distinguished, e.g., when they occupy distinct time bins or have different polarizations. Here we disproof this alleged straightforward link between indistinguishability and bunching by exploiting a recent finding in the theory of matrix permanents. We exhibit a family of optical circuits where the bunching of photons into two modes can be significantly boosted by making them partially distinguishable via an appropriate polarization pattern. This boosting effect is already visible in a 7-photon interferometric process, making the observation of this phenomenon within reach of current photonic technology. This unexpected behavior questions our understanding of multiparticle interference in the grey zone between indistinguishable bosons and classical particles.

Q 51.3 Thu 15:15 HS 1199

Superradiant bursts of light from cascaded quantum emitters: Experiment on photon-photon correlations — Constanze Bach, Christian Liedl, Arno Rauschenbeutel, •Philipp Schneeweiss, and Felix Tebbenjohanns — Department of Physics, Humboldt-Universität zu Berlin, Germany

Recently, superradiant bursts of light have been, for the first time, experimentally observed for a cascaded quantum system. This was realized using an ensemble of waveguide-coupled two-level atoms that exhibit chiral, i.e., propagation direction-dependent coupling to the waveguide mode. Here, we experimentally study this collective radiative decay of a fully inverted atomic ensemble and measure the second order quantum correlation function, $g^{(2)}(t_1, t_2)$, of the light emitted by the atoms into the waveguide. We observe $g^{(2)} \approx 2$ in the beginning of the decay ($t_1 = 0, t_2 = 0$), followed by a decrease to $g^{(2)}(t_1, t_2 = t_1) \approx 1$ within the characteristic time scale of the burst dynamics. This can be interpreted by assuming that, following an initially independent emission, the atoms synchronize during their decay, leading to an emission that more and more resembles the photon statistics of a coherent state. In addition to these observations, we find an anti-correlation of photon detection events, i.e., $g^{(2)}(t_1, t_2) < 1$, in certain parameter regions in which $t_1 \neq t_2$. Our measurement outcomes can be well described with a model based on the truncated Wigner approximation. Our findings contribute to understanding the fundamentals of light–matter interaction and help engineering protocols for the generation of non-classical light. [1] C. Liedl et al., arXiv:2211.08940

Q 51.4 Thu 15:30 HS 1199

Multiple Quantum Coherence signals by multilevel atoms with internal degeneracy — •Vyacheslav Shatokhin[1,2] and Andreas Buchleitner[1,2] — [1]Physikalisches Institut der Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing der Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Manifestations of dipole-dipole interactions in dilute thermal atomic vapors are difficult to sense, because of strong inhomogeneous broadening. Recent experiments with alkali-metal atoms revealed signatures of such interactions in fluorescence detection-based measurements of multiple quantum coherence (MQC) signals. We develop an open quantum systems theory of MQC signals in dilute thermal gases, which allows us to obtain good qualitative agreement with the experimental observations.

In the present talk, we outline the characteristic features of our theory which incorporates the vector character of the atomic dipoles, as well as driving laser pulses of arbitrary strength and polarization, includes the far-field coupling between the dipoles, which prevails in dilute ensembles, and effectively accounts for the atomic motion via a disorder average. We then discuss the impact of the multilevel internal structure of alkali-metal atoms on the fundamental properties of MQC signals.

Q 51.5 Thu 15:45 HS 1199

Large Deviation Statistics of Adiabatic Open Quantum Dynamics — •Paulo Paulino[1], Igor Lesanovsky[1,2], and Federico Carollo[1] — [1]Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

The state of an open quantum system undergoing an adiabatic process evolves by following the instantaneous stationary state of its time-dependent dynamical generator. This observation allows one to completely characterize, for generic adiabatic evolutions, the (average) master equation dynamics of the system. However, it does not provide information about the behavior of the system in single dynamical realizations, or single experimental runs. As a consequence, our understanding of full counting statistics of interesting quantities, such as the number of photons emitted by a slowly-driven optical system or the time-integrated stochastic entropy production in an adiabatic machine, remains rather limited. Here, we make progress in this direction and derive the full counting statistics of emission-related observables in generic adiabatic open quantum dynamics. We further compute the probability associated with any possible trajectory of the observable and devise a dynamics which can realize it as its typical behavior. Our findings provide a way to characterize and engineer adiabatic open quantum dynamics as well as to fully control their fluctuating behavior.

Q 51.6 Thu 16:00 HS 1199

Multi-particle Hong-Ou-Mandel interference with Ultracold Atoms — •Martin Quensen, Mareike Hetzel, and Carsten Klempt — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

Two photons, coupled by a 50:50 beamsplitter, always exit at the same output port. This effect was first observed in 1987 by Hong, Ou and Mandel and lies at the heart of quantum optics, as it describes the interference of single, indistinguishable bosons.

Here, we demonstrate this effect with massive particles instead of photons, and extend it to the interference of up to eight atoms at once. To achieve this, we employ spin-changing collisions in a Bose-Einstein condensate of Rb-87 and generate coherent superpositions of multiple twin-atom pairs. A dynamic, low-noise microwave source realizes the 50:50 beamsplitter-like coupling via Rabi oscillations. We use an optical-molasses-based detection setup to count the number of atoms in the output ports with single-atom accuracy.

The observation of the Hong-Ou-Mandel effect in our setup paves the way for the generation and analysis of entangled quantum states of massive particles with increasing fidelity and atom number. The concepts can be employed for realizing Heisenberg-limited atom interferometry with mesoscopic states of matter.

Q 51.7 Thu 16:15 HS 1199

Simulations of Hong-Ou-Mandel interference for parametric down-conversion in lossy waveguides — •Denis Kopylov[1,2], Polina Sharapova[1], Silia Babel[3], Laura Padberg[3], Michael Stefszky[3], Christine Silberhorn[3], and Torsten Meier[1,2] — [1]Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [2]Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [3]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Nowadays, parametric down-conversion (PDC) provides a flexible framework for the experimental realization of various types of non-classical light. Waveguide-based PDC sources are especially relevant for integrated quantum optical circuits, however imperfections of long nonlinear waveguides may lead to losses of the PDC field and consequently the desired quantum state cannot be realized exactly.

In this work we study numerically the Hong-Ou-Mandel (HOM) interference for PDC, generated in lossy nonlinear waveguides and show how the HOM interference pattern reveals the presence of losses. In our approach we solve the Heisenberg-Langevin equation for broadband multimode type-II PDC. Hong-Ou-Mandel interference is calculated in the framework of Gaussian states detected with click-detectors which allow us to study the non-perturbative PDC regime. The difference between internal waveguide losses and coupling losses of PDC on the HOM interference is demonstrated and analyzed.

Q 52: Structured Light

Time: Thursday 14:30–16:30 Location: HS 1221

Invited Talk Q 52.1 Thu 14:30 HS 1221

Structured light and its interaction with matter — •Robert Fickler, Rafael Barros, Lea Kopf, and Marco Ornigotti — Tampere University, Tampere, Finland

Shaping light fields in all degrees of freedom, i.e., space, time, and polarization, has become a versatile tool to explore fundamental optics effects and fruitful applications in various fields of photonics and quantum optics. In this talk, I will present some of our recent studies in this thriving branch of optics.

At first, I will discuss the behavior of light having optical phase vortices getting reflected off a planar surface. It was predicted that higher-order vortices split into a constellation of unit-charged vortices, a phenomenon which is related to fundamental optical beam shifts. We were able to observe this effect for the first time experimentally and proof that that the physical quantity of interest is the mathematical abstraction of elementary symmetric polynomials of the coordinates of a vortex constellation. Our results pave the path to novel material characterization techniques and might also find applications in other system exhibiting vortices, e.g., superfluids or Bose-Einstein condensates.

I will then present a simple experimental scheme to generate more complex states of light in which space, wavelength, and polarization are non-separable. We demonstrate that these so-called spatio-spectral vector beams can exhibit simultaneously all possible polarization states across their frequency spectrum and transverse spatial extent and point out interesting analogies to entangled tri-partite quantum systems.

Q 52.2 Thu 15:00 HS 1221

Orbital angular momentum modes generated in the parametric down-conversion process with a non-Gaussian pump — •Lucas Gehse, Dennis Scharwald, and Polina Sharapova — University Paderborn, Paderborn, Germany

Electric fields can carry two types of angular momentum. The first is the spin angular momentum, which arises from the polarization of the light, and the second is the orbital angular momentum (OAM) which arises from the light phase distribution. OAM modes have an unlimited basis, which makes them very promising for fast and efficient quantum information and communication protocols [1]. In this work, we investigate an SU(1,1) interferometer consisting of two PDC sources, which are two nonlinear crystals pumped by a Laguerre−Gaussian pump with different orbital and radial numbers. We consider various crystal lengths, pump widths and distances between the crystals, in order to find configurations with high-order OAM modes populated. We have found configurations in which the orbital Schmidt number can achieve $K_n = 101.31$. The orbital Schmidt number is defined as $K_n = \frac{1}{\sum_n \Lambda_n^2}$, where $\Lambda_n = \sum_m \lambda_{mn}$ is the weights of the orbital modes, with n being the orbital number and m - the radial number of Schmidt modes. Mode shapes and intensity profiles for various configurations of the SU(1,1) interferometer were investigated.

[1] Erhard *et al.*, Light Sci Appl **7**, 17146 (2018)

Q 52.3 Thu 15:15 HS 1221

Vortex-light Raman interaction with $^{40}Ca^+$ ion crystals — •Maurizio Verde[1], Benjamin Zenz[1], Ulrich Poschinger[1], Nicolas Nuñez[3], Christian Schmiegelow[3], and Ferdinand Schmidt-Kaler[1,2] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]Helmholtz-Institut Mainz, Mainz, Germany — [3]FCEyN, Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

Light beams carrying Orbital Angular Momentum (OAM) differently excite electronic and motional transitions of trapped atoms, and may thus be interesting for quantum optics, -sensing and -information processing. We experimentally demonstrated the transfer of transverse optical momentum to the quantized motion of a single $^{40}Ca^+$ ion [1] and provided a general theoretical framework to describe the light-matter interaction for spatially structured light [2]. Here, we investigate vortex light in the Raman scheme, where two beams excite trapped $^{40}Ca^+$ ions near 397nm and one of them is formed as a vortex beam with topological charge $l = +1$. We report on the Raman spectra for a single ion to determine the impact on its electronic and motional excitation. We extend this study for the orbital angular momentum transfer to two-ions crystals.

[1]Stopp et al., Phys. Rev. Lett. 129, 263603 (2022)
[2]Verde et al., arXiv:2306.17571 (2023), accepted on Sci. Rep.

Q 52.4 Thu 15:30 HS 1221

Universal crosstalk of structured light in random media — •David Bachmann[1], Asher Klug[2], Mathieu Isoard[1,3], Vyacheslav Shatokhin[1], Giacomo Sorelli[1,4], Andreas Buchleitner[1], and Andrew Forbes[2] — [1]Physikalisches Institut der Albert-

Ludwigs-Universität Freiburg — [2]University of the Witwatersrand, Johannesburg, South Africa — [3]Laboratoire Kastler Brossel, Paris, France — [4]Fraunhofer Institute for Optronics, Ettlingen, Germany

Structured light offers wider bandwidths and higher security for communication and strives to answer the growing demand of non-stationary links. However, propagation through complex random media, such as the Earth's atmosphere, typically induces crosstalk between spatial modes of light. We show numerically and experimentally that coupling of photonic orbital angular momentum (OAM) modes is governed by a universal function of a single parameter – the ratio between the random medium's and the beam's transverse correlation lengths, even in the regime of pronounced intensity fluctuations.

Q 52.5 Thu 15:45 HS 1221

Optimized generation of maximally entangled photon pairs in orbital angular momentum by simultaneous pump and crystal engineering — •Richard Bernecker[1,2], Baghdasar Baghdasaryan[2,3], and Stephan Fritzsche[1,2] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743, Jena, Germany — [2]Helmholtz-Institut Jena, Fröbelstieg 3, 07743, Jena, Germany — [3]Institut für Angewandte Physik, Friedrich-Schiller-Universität Jena, Albert-Einstein-Str. 6, 07745, Jena, Germany

Photon pairs generated from spontaneous parametric down-conversion (SPDC) are the predominant method to realize photonic entanglement. Laguerre-Gaussian modes, which carry orbital angular momentum (OAM), are commonly exploited to encode high-dimensional states experimentally. In particular, maximally entangled states (MES) in dimensions $d > 2$ show promising features like improving the capacity and security of quantum communication protocols. However, the direct generation of MES in higher-dimensional subspaces of the OAM basis remains a challenging task in the SPDC process. The manipulation of entangled OAM states by shaping the spatial profile of the pump beam and the increase of the single-photon purity by customized crystal-domain configurations have been demonstrated lately. We combine these both approaches and show theoretically that simultaneous pump and crystal engineering enables the direct preparation of full MES within OAM subspaces of varying dimensions.

Q 52.6 Thu 16:00 HS 1221

Scalable Generation of Continuous Variable Multipartite Quantum Correlated States of Light — •Daida Thomas[1,2], Saesun Kim[1,2], and Alberto Marino[1,2,3,4] — [1]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, 73019, USA — [2]Center for Quantum Research and Technology, University of Oklahoma, Norman, OK, 73019, USA — [3]Quantum Information Science Section, Computational Sciences and Engineering Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA — [4]Quantum Science Center, Oak Ridge National Laboratory, Oak Ridge, TN 37381, USA

Continuous variable (CV) entangled states of light serve as the foundation for a number of applications in quantum information science, such as quantum sensing, quantum computing, and quantum networking. To build a long distance multichannel quantum network or the resource states for CV quantum computing, multi-partite entangled states are needed. Here we report on the experimental scalable generation of CV multi-partite quantum correlated states. To this end, we leverage the multi-spatial mode properties of four wave mixing to implement a modified SU(1,1) interferometer that introduces quantum correlations between the different spatial modes. The expected quantum correlations involving conjugate variables are analyzed in terms of squeezing for all possible bipartitions. These results represent a first step toward the generation of multi-partite entangled states in connected graph states and show the expected connectivity of the graph.

Q 52.7 Thu 16:15 HS 1221

Image resolution of quantum imaging with undetected light — •René Sondenheimer[1,2] and Marta Gilaberte Basset[2,3] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745, Jena, Germany — [3]Institute of Applied Physics, Abbe Center of Photonics, Friedrich-Schiller-University Jena, Albert-Einstein-Str. 6, 07745, Jena, Germany

Image resolution of quantum imaging with undetected photons is governed by the spatial correlations existing between the photons of a photon pair that has been generated in a nonlinear process. These correlations allow for obtaining an image of an object with light that never interacted with that object. Depending on the imaging configuration, either position or momentum correlations can be exploited. We analyze how different source parameters affect the image resolution when using spatial correlations of photons that have been generated via spontaneous parametric down conversion in a nonlinear interferometer. In particular, we discuss the intricate dependency of the resolution on the strength of the correlations within the biphoton states.

Q 53: Quantum Control

Time: Thursday 14:30–16:30 Location: HS 3118

Q 53.1 Thu 14:30 HS 3118

Quantum Control on a Quantum Computer: Theory and experiment — •Nikolay Vitanov — Sofia University, Bulgaria

Recent results from quantum control experiments on some quantum processors offered by IBM Quantum will be reported. The experiments have been performed using the back-end Qiskit Pulse package, which offers full control over the experimental parameters: pulse amplitude, frequency, phase and shape. The results include the demonstration of composite pulses - trains of pulses with well-defined relative phases used as control parameters - for complete (X gates) and partial (Hadamard and general rotation gates) population inversion, which cancel the experimental errors to an arbitrary order. Another example is the newly proposed quantum control technique of polychromatic pulse trains - sequences of pulses of different appropriately chosen frequencies used, instead of the phases, as control parameters.

Conventional wisdom suggests that the excitation line profile should broaden when the Rabi frequency increases - this is the textbook effect of power broadening. Earlier work demonstrated that power broadening may not occur in pulsed excitation and revealed the near absence of power broadening in excitation by Gaussian pulses. Quite remarkably, we have observed the counterintuitive phenomenon of power narrowing with driving pulses of Lorentzian shape - the squeezing of the excitation line profile when the Rabi frequency increases. While this stunning effect had been predicted earlier it has never been observed in an experiment.

Q 53.2 Thu 14:45 HS 3118

Determining the ability for universal quantum computing: Testing controllability via dimensional expressivity — •Fernando Gago-Encinas[1], Tobias Hartung[2,3], Daniel M. Reich[1], Karl Jansen[4], and Christiane P. Koch[1] — [1]Freie Universität Berlin, Berlin, Germany — [2]Northeastern University London, London, United Kingdom — [3]Northeastern University, Boston, Massachusetts, USA — [4]NIC, DESY, Zeuthen, Germany

Universal quantum computing requires a quantum system that is operator-controllable. However, the number of resources required for controllability in complex systems is not obvious and, moreover, assessing this property on the systems themselves is a difficult task to achieve in practice. In this project we present a hybrid quantum-classical algorithm, uniting quantum measurements and classical calculations.

The key to our approach is the design of a parametrized quantum circuit (PQC), which can be run on the original system with some auxiliary qubits. By applying dimensional expressivity analysis we are able to count the number of independent parameters in the PQC. This represents the dimensional expressivity of the PQC, which is then linked back to the controllability of the initial system.

Q 53.3 Thu 15:00 HS 3118

Optimizing bosonic two-qubit quantum gates — •Marcus Meschede[1] and Ludwig Mathey[1,2] — [1]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

Qubits that are encoded in the bosonic modes of cavities have emerged as a compelling platform for robust quantum computing. This is due to their high dimensional encoding of the logical qubit states, for which several error correcting schemes exist. Circuit and cavity QED setups realize this system through microwave cavities, coupled by additional ancillary transmon qubits. In this work, we optimize local driving pulses of the cavities and the transmon in order to implement two qubit quantum gates. We evaluate different choices for the logical qubit encoding in the presence of realistic decoherence processes and find high-fidelity quantum gate implementations.

Q 53.4 Thu 15:15 HS 3118

Applying optimal control to atomic quantum simulators — •Matthias Hüls[1], Robert Zeier[1], Felix Motzoi[1], and Tommaso Calarco[1,2,3] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), Jülich 52425, Germany — [2]Institute for Theoretical Physics, University of Cologne, Köln 50937, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

We study how optimal control can enhance the efficiency and robustness of atomic quantum simulators. We develop effective control pulses adapted to experimental platforms based on neutral atoms in optical lattices and Rydberg atoms. We compare optimization techniques using model-based numerical simulations and black-box feedback directly operating on the experimental setup. We employ the quantum-control software library QuOCS [1] which provides a unified framework for applying control algorithms such as d-CRAB and GRAPE. We highlight how technical and experimental challenges influence the choice of control techniques.

[1] M. Rossignolo, T. Reisser, A. Marshall, P. Rembold, A. Pagano, P. J. Vetter, R. S. Said, M. M. Mueller, F. Motzoi, T. Calarco, F. Jelezko, and S. Montangero, "Quocs: The quantum optimal control suite", Comuputer Physics Communications 291, 108782 (2023), https://doi.org/10.1016/j.cpc.2023.108782

Q 53.5 Thu 15:30 HS 3118

Simulation and optimization methods for collision gates with ultra-cold atoms — •Jan Reuter[1,2], Tommaso Calarco[1,2,3], Felix Motzoi[1,2], and Robert Zeier[1] — [1]Peter Grünberg Institute - Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, Wilhelm-Johnen-Straße, 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Cologne, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Atoms in an optical lattice can be used for various applications of quantum technologies, including quantum simulators or quantum computers. In our study, we simulate fermionic ^{6}Li atoms in an optical lattice using a split-step method to solve the Schrödinger equation in up to three dimensions. We analyze the behavior of one, two or three atoms in a double-well potential in a 1D-confinement under the influence of a SWAP- or $\sqrt{\text{SWAP}}$-gate. For this task, we optimize our time-dependent controls by simulating the gradient and the Hessian matrix of the quantum state with respect to these controls. Furthermore, we can verify our results by showing that the simulation of a two-atom collision in a 1D-confinement agrees with the result of a corresponding simulation assuming a 2D-confinement with a tight potential in one of these dimensions.

Q 53.6 Thu 15:45 HS 3118

Optimal control methods for two-qubit gates in optical lattices — •Juhi Singh[1,2], Felix Motzoi[1], Tommaso Calarco[1,2,3], and Robert Zeier[1] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

We use quantum optimal control to identify fast collision-based two-qubit gates in ultracold atoms trapped in superlattices based on classical Fermi-Hubbard simulations. We manipulate the hopping and interaction strengths inherent in the Fermi-Hubbard model by optimizing the lattice depth and the scattering length. We show that a significant speedup can be achieved by optimizing the lattice depths in a time-dependent manner, as opposed to maintaining a fixed depth. We obtain non-adiabatic fast gates by including higher bands of the Hubbard model in the optimization. Furthermore, in addition to two-qubit states, our optimized control pulses retain their effectiveness for one, three, or four atoms in the superlattice. We compare our Fermi-Hubbard approach with real-space simulations using Wannier functions.

Q 53.7 Thu 16:00 HS 3118

Atom transport optimization: theoretical frameworks, control algorithms, and experimental integration. — •Cristina Cicali[1,2], Robert Zeier[1], Felix Motzoi[1,2], and Tommaso Calarco[1,2,3] — [1]Forschungszentrum Jülich,Peter Grünberg Institute, Quantum Control (PGI-8), 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Ultracold atoms constitute a promising platform for quantum computing and quantum simulation. We study the transport of individual atoms in optical tweezers using methods of optimal control. As part of the BMBF project FemiQP, we are developing a theoretical framework for numerically optimizing atom transport trajectories, including strategies aimed at maximizing the transport fidelity, velocity, and robustness against experimental imperfections. Quantum control algorithms such as the dressed-CRAB (d-CRAB) and Gradient Ascent Pulse Engineering (GRAPE) are compared with regard to their utility to effectively optimize the atom transport. In collaboration with the group Christian Groß, optimized control protocols are adapted to the experimental platform in Tübingen.

Q 53.8 Thu 16:15 HS 3118

Quantum Error Correction with Quantum Autoencoders — •Diego Alberto Olvera Millán[1], David Locher[2,3], Lorenzo Cardarelli[4], Janine Hilder[1], Markus Müller[2,3], Ulrich Poschinger[1], and Ferdinand Schmidt-Kaler[1] — [1]Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich, D-52425 Jülich — [3]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [4]Pasqal, 7 Rue Leonard de Vinci, 91300 Massy, France

Active quantum error correction is a critical element in realizing robust quantum computation. Quantum Autoencoders have the potential for discovering error correction algorithms [1]. Our study aims to transition this theoretical framework into practical hardware implementation. Our approach involves a trainable circuit. This parameterized ansatz was trained in a simulator backend and subsequently validated on a shuttling-based trapped-ion quantum computer. Future work will center around performing training using the Quantum computer to evaluate the cost function and finding codes for correcting the native error sources of the hardware.

Q 54: Quantum Optics in Space

Time: Thursday 14:30–16:30 Location: HS 3219

Q 54.1 Thu 14:30 HS 3219

Two-Beam Interference in Rindler Spacetime — •Yatin Kumar Jaiswal[1,2] and Sebastian Ulbricht[1,2] — [1]Physikalisch Technische Bundesanstalt, Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany

The study of polarized light in curved spacetime has been a promising endeavour in the past with theoretical predictions like the gravitational analogue of the Faraday effect and the Spin Hall effect. Motivated by these successes, we conduct a similar investigation for light propagation in Earth's gravity at laboratory scales. One way to do that is to model Earth's local gravity as spacetime perceived by a homogeneously accelerated observer, i.e., the Rindler Spacetime. This model is justified because the Equivalence Principle posits that experiments done in a constantly accelerated frame or in a homogenous gravitational field are indistinguishable. In this contribution, we study the propagation of light in Rindler Spacetime and investigate the interference of two light waves with arbitrary polarizations in the Geometrical Optics regime. We present the most general expression of the Stress-Energy tensor in this spacetime to linear order in gL/c^2, where L is a typical length scale of table-top experiments. Further, we analyze the Poynting vector, i.e., the intensity and its dependence on polarization, as well as the orientations and wavelengths of the interfering beams.

Q 54.2 Thu 14:45 HS 3219

Space Magnetic Gradiometry using Atom Interferometers — •Gabriel Müller[1], Timothé Estrampes[1,2], Annie Pichery[1,2], Nicholas P. Bigelow[3], Naceur Gaaloul[1], and the CUAS Consortium[3] — [1]Leibniz University Hannover, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, France — [3]University of Rochester, USA

Quantum Sensing is becoming a valuable tool for several applications such as gravity sensing, inertial navigation or magnetometry. Atom Interferometry (AI), a pillar of quantum sensing, has been successfully demonstrated in the lab and field settings.

Here, we report on pioneering AI experiments operated in NASA's Cold Atom Lab (CAL) onboard the International Space Station [E. Elliott et al., Nature 623, 502 (2023)]. In this unique microgravity environment, we prepare ^{87}Rb condensed clouds and utilise them in various atom interferometric schemes. This allows to measure local magnetic potential curvatures and detect tiny residual differential magnetic forces, thereby outperforming the sensitivity of classical methods.

These results pave the way to future Space missions leveraging AI sensors such as for Space Magnetometry. Moreover, we discuss strategies to overcome current sensitivity-limiting factors by improving the AI laser beam optical quality or the atom number as planned for the recently installed CAL upgrade Science Module SM3B.

Acknowledgements: Funded by the German Space Agency (DLR) with funds under Grant No. 50WM2245A (CAL-II).

Q 54.3 Thu 15:00 HS 3219

Quantum gas mixtures in an Earth-orbiting research laboratory — •Annie Pichery[1,2], Timothé Estrampes[1,2], Gabriel Müller[1], Nicholas P. Bigelow[3], Eric Charron[2], Naceur Gaaloul[1], and the CUAS Consortium[3] — [1]Leibniz Universität Hannover,Institut für Quantenoptik, Germany — [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France — [3]University of Rochester, Rochester, NY, USA

The Cold Atom Laboratory (CAL) is a multi-user Bose-Einstein Condensate (BEC) machine aboard the International Space Station, operated by NASA's Jet Propultion Lab. Since its upgrade in 2020, it enables the production and manipulation of dual-species BEC mixtures of K and Rb. We report here about the first quantum mixture experiments realized in space [E. Elliott et al., Nature 623, 502 (2023)] and study its dynamics in weightlessness to prepare dual-species atom interferometry and future tests of the Universality of Free Fall.

Space provides, indeed, an environment where atom clouds can float for extended times of several seconds, as well as miscibility conditions different from ground. Simulating these quantum phases and the dynamics of interacting dual species presents however computational challenges due to the long expansion times. We present a novel theoretical framework based on re-scaled computation grids that allowed to follow the extended free dynamics of quantum mixtures in space.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under Grant No. CAL-II 50WM2245A/B.

Q 54.4 Thu 15:15 HS 3219

Status of the Laser System for Cold Atom Experiments in BECCAL onboard the ISS — •Hamish Beck[1], Hrudya Thaivalappil Sunilkumar[1], Marc Kitzmann[1], Matthias Schoch[1], Christoph Weise[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Jakob Pohl[1], Achim Peters[1], and the BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hanover — [5]DLR-SI, Hanover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR-SC, Braunschweig

The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is designed for operation onboard the International Space Station (ISS). This multi-user facility will enable experiments with K and Rb ultra-cold atoms and BECs in mircogravity. Fundamental physics will be explored at longer time- and lower energy-scales compared to those achieved on earth.

The BECCAL laser system is comprised of micro-integrated diode lasers, miniaturized free-space optics on Zerodur boards, and a system of fibres to bring light to the physics package. The design is subject to strict size, weight, and power (SWaP) constraints, and the operation of the system is supported by extensive ground-based systems.

An update on the progress of the laser system will be given, touching upon the flight model design and the status of ground-based systems built from commercial components.

This work is supported by the DLR with funds provided by the BMWK under grant number 50WP2102.

Q 54.5 Thu 15:30 HS 3219

Compact and robust design of a crossed optical dipole trap for space application — •Jan Simon Haase[1], Janina Hamann[1], Alexander Fieguth[2], Jens Kruse[2], Carsten Klempt[1,2], and The INTENTAS Team[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstraße 30b, 30167 Hannover

Towards the implementation of atom interferometry in commercial sensors, improvements of the current systems in compactness and robustness are a next necessary step. Also, for applications in space it is urgent to compactify the sensors and make them robust against accelerations and vibrations.

In the INTENTAS project (Interferometry with entangled atoms in space) evaporative cooling in a novel, optical dipole trap will be used to create Bose-Einstein condensates in a microgravity environment. The project will demonstrate a compact source of entangled atoms in the Einstein-Elevator, a microgravity platform which allows zero-gravity tests for up to 4 s. The planned experiments will pave the way to employ entangled atomic sources for high-precision interferometry in space applications.

In this talk, the novel design of the optical dipole trap is presented. Simulations of the beam deformation and measurements from first flight tests are shown.

Q 54.6 Thu 15:45 HS 3219

QUBE-II: Towards Quantum Key Distribution between a CubeSat and Ground — •Jonas Pudelko for the QUBE-II-Collaboration — Friedrich-Alexander-Universität Erlangen-Nürnberg, Lehrstuhl für optische Quantentechnologien, Staudtstr. 7/B2, D-91058 Erlangen, Germany — Max Planck Institute for the Science of Light, Staudtstr. 2, D-91058 Erlangen, Germany

The limited range of quantum key distribution (QKD) in fiber based systems has led to several projects aiming for the development of a satellite based QKD infrastructure, like the MICIUS mission, which impressively demonstrated QKD on a global scale. However, the high costs of satellite launches for such a system can be reduces dramatically by further reduction in size, weight and power.

The QUBE-II mission is designed to perform the first QKD exchange between a small 8U CubeSat ($10 \times 20 \times 40$ cm^3) and a ground station. Based on the predecessor mission QUBE, two enhanced integrated QKD transmitters implement polarization and phase based versions of the BB84 decoy protocol. Both transmitters are managed by a protocol board, which is using a photonically integrated quantum random number generator as an entropy source. The quantum states are transmitted via an optical telescope with aperture size of 80 mm, which is also used to establish a bi-directional classical data link for post processing.

In this work, we will present the mission concept and discuss the challenges of performing quantum optic experiments on a CubeSat in space.

Q 54.7 Thu 16:00 HS 3219

Time Synchronization in Satellite and Long Distance Quantum Communication — •Pritom Paul[1,2], Christopher Spiess[1,2], and Fabian Steinlechner[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Str. 07, 07745 Jena, Germany. — [2]Friedrich Schiller University, Institute of Applied Physics, Albert-Einstein-Str. 15, 07745 Jena, Germany.

To establish quantum communication, it is crucial to accurately identify and resolve single photon detection events. Issues arise in space-based and long-distance quantum communication systems, where achieving secure communication and picosecond timing accuracy is hindered by low signal-to-noise ratio resulting from propagation loss and atmospheric turbulence. The signal to noise ratio of the synchronization signal improves by the introduction an attenuated pulsed laser from which the timing offset could be determined by its own single photon detection events. Using time multiplexing, the pulsed signal can be isolated from the quantum signal, thereby facilitating the identification of synchronization windows within the detected signal.

In this work we develop a synchronization protocol involving an attenuated pulsed laser combined to the output of an entangled photon source and detected using superconducting nanowire single-photon detectors. Next, we introduce channel losses to emulate a real-world quantum network. This reflects scenarios with substantial node distances, incorporating losses attributed to atmospheric turbulence, particularly in the context of satellite and free space-based networks.

Q 54.8 Thu 16:15 HS 3219

Angular Bloch Oscillations and their applications — •Bernd Konrad and Maxim Efremov — German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

Inspired by the fast-developing field of compact and mobile quantum sensors for space- and ground-based applications, we propose a new concept for measuring the angular acceleration of external rotation. For this, we study the dynamics of ultra-cold atoms in a toroidal trap with additional modulation along the angular direction, realized in labs with the superposition of two Laguerre-Gauss (LG) beams with indices l and $-l$. In the presence of external rotation with small angular acceleration, or by having a well-controllable chirp between the two LG beams, our system is shown to display a new phenomenon we name as the Angular Bloch Oscillations (ABOs). In addition, we show that ABOs can be utilized (i) to precisely transfer certain angular momenta (multiples of $2l\hbar$) from the field to trapped atoms, by using the slowly varying chirp, and (ii) to determine the angular acceleration of the external rotation, by measuring the Bloch period of ABOs.

Q 55: Poster VI

Time: Thursday 17:00–19:00 Location: Tent B

Q 55.1 Thu 17:00 Tent B

Enhanced laser systems for photoassociation spectroscopy and cold Hg atoms — •Rudolf Homm and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Cold Hg atoms in a magneto-optical trap offer opportunities for various experiments. The two stable fermionic isotopes are of interest for a new time standard based on an optical lattice clock employing the $^1S_0$ - $^3P_0$ transition at 265.6 nm. All stable isotopes can be used to form ultracold Hg dimers by photoassociation combined with vibrational cooling by applying a specific excitation scheme.

Our experimental setup consists of two UV laser systems and a magneto-optical trap for Hg atoms with a 2D-MOT for preselection of the desired isotopes. Both laser systems consist of a MOFA setup followed by two successive frequency doubling stages.

The cooling laser aims for stabilization at a fixed frequency and high output power. Therefore, we use Doppler-free saturation spectroscopy and a frequency doubling stage with an elliptical focus in the crystal. We can now produce more than 1 W at 253.7 nm without any sign of degradation in the BBO crystal.

We improved the output power of the spectroscopy laser to over 200 mW at 254.1 nm and are installing a feed-forward setup for the frequency doubling cavities to match the tuning range of the ECDL.

We will report on the status of the experiments.

Q 55.2 Thu 17:00 Tent B

Machine Learning techniques in Quantum Gas Transport Experiments — •Gabriel Müller[1], Victor J. Martínez-Lahuerta[1], Philipp-Immanuel Schneider[2,3], Ivan Sekulic[2,3], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Germany — [2]JCMwave GmbH, Berlin, Germany — [3]Zuse Institute Berlin, Germany

Precision atom interferometry (AI) requires an accurate quantum state engineering of the atomic ensembles at the input port. With Bose-Einstein Condensates (BECs), quick and robust transports have been experimentally realised using shortcut to adiabaticity (STA) protocols [N. Gaaloul et al., *Nature communications* 13(1), 7889 (2022)]. These STA protocols, however, as well as alternative approaches featuring Optimal Control Theory (OCT) [S. Amri et al. *Scientific Reports* 9(1), 5346 (2019)], are either limited by approximations to avoid expensive computations or by a limited number of control parameters.

To address these limitations, we propose a novel approach that utilises Bayesian optimisation with Gaussian processes as machine learning surrogates. We evaluate its level of control in comparison to STA and OCT methods and later extend the application to reduce the amount of approximations and open up more degrees of freedom.

Once these methods are verified, one could consider dual-species transport and improve its robustness by taking into account experimental imperfections on ground and in microgravity.

Acknowledgements: Funded by the German Space Agency (DLR) with funds under Grant No. 50WM2253A/B (AI-quadrat).

Q 55.3 Thu 17:00 Tent B

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

The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is a cold atom experiment designed for operation onboard the ISS. This multi-user facility will enable the exploration of fundamental physics with Rb and K BECs and ultra-cold atoms in microgravity, facilitating prolonged time- and ultra-low energy scales.

BECCAL must be operable without intervention for three years on the ISS. To reach that goal and match the stringent SWaP limitations, we have to fulfill strict product assurance requirements for the complex laser system. This not only involves higher cleanliness and ESD standards but also demands a meticulous integration process. To navigate this, the use of prototypes becomes imperative. In this context, the first essential integration tests, along with the adaptations made, based on the experience gained, will be presented.

This work is supported by the DLR with funds provided by the BMWK under grant number 50WP2102.

Q 55.4 Thu 17:00 Tent B

Optical zerodur bench system for the BECCAL ISS quantum gas experiment — •Faruk Alexander Sellami[1], André Wenzlawski[1], Esther del Pino Rosendo[1], Jean Pierre Maburger[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and THE BECCAL TEAM[1,2,3,4,5,6,7,8,9,10,11] — [1]Institut für Physik, JGU Mainz — [2]ILP, Universität Hamburg — [3]Institut für Physik, HUB — [4]FBH, Berlin — [5]IQ & IMS, LUH, Hannover — [6]ZARM, Bremen — [7]Institut für Quantenoptik, Universität Ulm — [8]DLR-SC, Braunschweig — [9]DLR-SI, Hannover — [10]DLR-QT, Ulm — [11]OHB-SE, Bremen

The NASA-DLR collaboration BECCAL will be a multi-user-multi-purpose facility for the study of Bose Einstein Condensates in the microgravity environment of the International Space station. Its laser system provides light distribution and frequency stabilization and must be robust and compact to withstand the rocket launch and temperature fluctuations during the runtime on the ISS. To this end a toolkit based on the glass ceramic Zerodur is developed, that has already successfully been used on numerous space missions like FOKUS, KALEXUS or MAIUS. This poster discusses the optical modules developed and tested for BECCAL. Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWK) under grant number 50 WP1433, 50 WP 1703 and 50 WP 2103.

Q 55.5 Thu 17:00 Tent B

Purcell modified Doppler cooling of quantum emitters inside optical cavities — •Julian Lyne[1,2], Nico Bassler[1,2], Seong eun Park[3], Guido Pupillo[4], and Claudiu Genes[2,1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany — [3]Daegu Gyeongbuk Institute of Science and Technology,333 Techno jungang-daero, Hyeonpung-eup, Dalseong-gun, Daegu, South Korea — [4]Centre Européen de Sciences Quantiques (CESQ), Institut de Science et d' Ingénierie Supramoléculaires (ISIS) (UMR7006) and Atomic Quantum Computing as a Service (aQCess), University of Strasbourg and CNRS, Strasbourg 67000, France

Standard cavity cooling of atoms or dielectric particles is based on the action of dispersive optical forces in high-finesse cavities. We investigate here a complementary regime characterized by large cavity losses, resembling the standard Doppler cooling technique. For a single two-level emitter a modification of the cooling rate is obtained from the Purcell enhancement of spontaneous emission in the large cooperativity limit. This mechanism is aimed at cooling of quantum emitters without closed transitions, which is the case for molecular systems, where the Purcell effect can mitigate the loss of population from the cooling cycle. We extend our analytical formulation to the many particle case governed by weak individual coupling but exhibiting collective strong Purcell enhancement to a cavity mode.

Q 55.6 Thu 17:00 Tent B

Laser system Designs in BECCAL for Cold Atom Experiments on ISS — •Hrudya Thaivalappil Sunilkumar[1], Jakob Pohl[1,2], Matthias Schoch[1], Christoph Weise[1], Hamish Beck[1], Marc Kitzmann[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Achim Peters[1,2], and The BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hannover — [5]DLR-SI, Hannover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR, Braunschweig

Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is a multi-user facility designed for operation on the ISS. This DLR and NASA collaboration enables the exploration of fundamental physics with Rb and K BECs and ultra-cold atoms in microgravity, facilitating prolonged timescales and ultra-low energy scales.

A ground-based replicate of the apparatus must also be built to support the operation of the flying experiment. The size, weight, and power constraints of such a Ground-based Test Bed (GTB) are relaxed, and so the laser system may be made from Commercial Off-The-Shelf (COTS) components. The design of this GTB laser system will be presented alongside the design of the flight hardware for a direct comparison.

Funding by DLR / BMWK grant numbers 50 WP 2102, 2103, 2104.

Q 55.7 Thu 17:00 Tent B

Two-dimensional grating magneto-optical trap — •Joseph Muchovo[1], Hendrik Heine[1], Aaditya Mishra[1], Julian Lemburg[1], Kai-Christian Bruna[1], Waldemar Herr[1,2], Christian Schubert[1,2], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Intertialsensorik (SI)

Ultracold atoms provide exciting opportunities for matterwave interferometry and tests of fundamental physics. When used as separate source chambers, Two-dimensional (2D) magneto-optical traps MOTs are advantageous in pre-cooling and faster loading of atoms to three-dimensional grating MOTs. To realise field applications of quantum sensors utilising cold atoms, there is need for simpler, more efficient and more compact sources.

In this poster, we will present the design, simulation and implementation of a 2D grating MOT requiring only a single input cooling beam. This will lead to a robust, compact and efficient source of ultracold atoms that can be used in field and space applications.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate protection (BMWK) due to the enactment of the German Bundestag under grant number DLR 50RK1978 (QCHIP) and by the German Science Foundation (DFG) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967.

Q 55.8 Thu 17:00 Tent B

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

Atom interferometry with Bose-Einstein condensates enables very precise measurements of gravity with residual uncertainties on the order of nm/s^2. A low size, weight, and power consumption are essential for potential applications like ground or space-borne geodesy. This challenge can be tackled by using atom chips as they offer the desired magnetic fields at low power. Additionally, the atom chip can be equipped with a grating to facilitate the creation of a magneto-optical trap with a single beam or with a mirror for Raman interferometry.

In this poster, we will present a concept for a novel atom chip that combines the features of the grating and the mirror, that allows us to reduce the sensor head to shoe-box size. With this novel atom chip and an additional relaunch scheme an innovative single-beam quantum gravimeter is envisaged. Through the miniaturization and reduction of complexity of the sensor head, the transportability and usability of the quantum gravimeter are enhanced and ease in-field operations.

This work is funded by the German Research Foundation (DFG) in the CRC 1464 "TerraQ" (Project A03) and under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 55.9 Thu 17:00 Tent B

Assessing interactions of Rb vapor with mirror coatings — •Constantin Avvacumov, Alexander Herbst, Klaus Zipfel, Ali Lezeik, Dorothee Tell, Jonas Klussmeyer, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Atom interferometers are effective tools for fundamental research and geodesy applications, e.g. for gravimetry. Fundamentally, quantum projection noise motivates the development of high-flux sources of cold atoms. A typical first cooling stage is a two-dimensional magneto-optical trap (2D-MOT). In recent years, attempts to improve on 2D-MOTs' SWaP (size, weight, and power) budget raised questions regarding the compatibility of high-quality optical coatings exposed to alkali vapor, e.g. rubidium or potassium.

In this work, we systematically analyse the interaction of Rb vapor with highly reflective coating materials (gold, silver, aluminium, dielectric coatings). Our mirror testing setup enables simultaneous exposure of multiple mirror samples to a high flux of Rb atoms and measurement of their reflectivity degradation as a function of time and alcali partial pressure. The results will yield better understanding of the reactivity of alkali vapor with various materials and will thus be useful for future compact quantum optical experiments.

Q 55.10 Thu 17:00 Tent B

Comparison of Laser system Designs in BECCAL for Cold Atom Experiments on ISS — •Hrudya Thaivalappil Sunilkumar[1], Hamish Beck[1], Marc Kitzmann[1], Matthias Schoch[1], Christoph Weise[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Jakob Pohl[1], Achim Peters[1], and The BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hannover — [5]DLR-SI, Hannover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR- SC, Braunschweig

Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is a multi-user facility designed for operation on the ISS. This DLR and NASA collaboration enables the exploration of fundamental physics with Rb and K BECs and ultra-cold atoms in microgravity, facilitating prolonged timescales and ultra-low energy scales.

A ground-based replicate of the apparatus must also be built to support the operation of the experiment. The size, weight, and power constraints of such a Ground-based Test Bed (GTB) are relaxed, and so the laser system may be made from Commercial Off-The-Shelf (COTS) components. The design of this GTB laser system will be presented alongside the design of the flight hardware for a direct comparison.

This work is supported by the DLR with funds provided by the BMWK under grant number 50WP2102.

Q 55.11 Thu 17:00 Tent B

Driving Raman transitions using a nano-structured atom chip — •Kai-Christian Bruns[1], Julian Lemburg[1], Hendrik Heine[1], Joseph Muchovo[1], Aaditya Mishra[1], Waldemar Herr[2], Christian Schubert[2], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik (SI)

In the field of quantum sensing, atom interferometers are a crucial tool for high-resolution measurements. Unfortunately, current systems remain bulky and power consuming making them unreliable for field applications. Grating atom chips simplify quantum sensors by enabling the trapping of atoms in a MOT with a single incident beam.

In this poster, we show measurements of Raman transitions on an atom chip with a grating with a single incident modulated laser beam as well as simulations, which support the results. Using the diffracted beams from the grating in combination with the incoming beam, we can drive Raman transitions along different axes allowing for the construction of a compact multi-axis atom interferometer.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate protection (BMWK) due to the enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS II), by the German Research Foundation (DFG) in the CRC 1464 'TerraQ' (Project A03) and from 'QVLS-Q1' through the VW foundation and the ministry for science and culture of Lower Saxony.

Q 55.12 Thu 17:00 Tent B

The MAIUS-2 laser system — •Pawel Arciszewski[1], Klaus Döringshoff[1], Achim Peters[1], and The MAIUS Team[1,2,3,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]ZARM, Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation, Bremen — [4]Institut für Physik, JGU Mainz — [5]IQO, Leibniz Universität Hannover

The first production of a Bose-Einstein condensate in space carried out in the MAIUS-1 sounding rocket mission in January 2017 paved the way for more advanced experiments with ultra-cold matter in space. The goal of the MAIUS-2 mission is the creation of mixtures of ultracold rubidium and potassium atoms onboard a sounding rocket.

To this end, an advanced laser system was developed, that can provide the light required for simultaneous laser cooling of rubidium and potassium as well as imaging of the Bose-Einstein condensates. The system was realized and qualified to meet the demands of a sounding rocket mission.

We report on the performance of the system, its assembly process, the used technologies as well as tests carried out to assure that the laser system can face the needs of the mission.

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 50 WP 1432.

Q 55.13 Thu 17:00 Tent B

PRIMUS - all-optical source of ultracold rubidium atoms for microgravity — •Marian Woltmann[1], Jan Eric Stiehler[1], Marius Prinz[1], Sven Herrmann[1], and The PRIMUS-Team[1,2] — [1]Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Germany — [2]Institute of Quantum Optics, LU Hannover, Germany

Atom interferometers based on ultracold atoms have proven to be effective tools in measuring weakest forces. As their sensitivity scales with the squared interrogation time, the application of matter wave interferometers in microgravity offers the potential of highly increased sensitivities. While many cold-atom based microgravity-experiments use magnetic chip traps, the PRIMUS-project develops an all-optical trap as an alternative source of ultracold rubidium atoms in a drop tower experiment. Solely using optical potentials offers unique advantages, e.g. improved trap symmetry, trapping of all magnetic sub-levels and the accessibility of Feshbach resonances. We demonstrated rapid Bose-Einstein condensation of ^{87}Rb in less than two seconds on ground while now focusing on the optimization for an efficient preparation in microgravity. The PRIMUS-project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50 WM 2042.

Q 55.14 Thu 17:00 Tent B

Experimental realization of a two-dimensional sodium potassium mixture — •Brian Bostwick, Anton Eberhardt, Malaika Göritz, Lilo Höcker, Jan Kilinc, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff Institut für Physik, Heidelberg, Deutschland

Multiple-species Bose-Einstein condensates provide versatile platforms for many-body quantum dynamics. Mixtures of sodium and potassium are particularly attractive due to the substantial interspecies and intraspecies Feshbach resonances, providing a broad range of tunability via magnetic fields. Experiments in reduced dimensions enable probing the excitations on the atomic cloud with high spatial resolution. We show the latest developments of our experimental setup for the production and imaging of a dual-species Bose-Einstein condensate in 2D.

Q 55.15 Thu 17:00 Tent B

An ion-trap chip with integrated elements for a scalable quantum processor — •Benjamin Bürger, Ivan Boldin, Christof Wunderlich, Saptarshi Biswas, and Daniel Busch — University of Siegen, Germany

Scaling up a trapped ion-based quantum information processing to hundreds of qubits could be achieved by arranging several trapping zones on an ion-trap-chip. The zones can be entangled by means of shuttling ions between the zones [1]. Here, we use hyperfine levels as qubits of 171Yb+ ions trapped in a planar microstructured trap with MAgnetic Gradient Induced Coupling (MAGIC) between them [2]. We report on the design and characterization of this novel trap chip that includes an integrated microwave electrode for efficient single-qubit manipulations, permanent magnets for creating a field gradient of 100 T/m required for multi-qubit gates via MAGIC, and an ion transport zone for testing the qubit coherence properties when shuttling the ion in and out of the interaction zone. The trap chip is designed to serve as a basis for a up-scalable device.

References:

[1] D. Kielpinski, C. Monroe and D. J. Wineland, Nature 2002 Vol. 417 Pages 709-711

[2] Piltz et al 2016

Q 55.16 Thu 17:00 Tent B

Towards Sympathetic Cooling of Ytterbium Ions Using Sub-Doppler Cooled Barium Ions in a Novel Planar Micro-Structured Segmented Linear Paul Trap — •Pedram Yaghoubi, Florian Köppen, Ernst Alfred Hackler, Dorna Niroomand, Michael Johanning, and Christof Wunderlich — Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany

Sympathetic cooling of trapped ions in an inhomogeneous magnetic field is important for various applications in quantum information processing, quantum simulation, and precision measurements. We work towards sub-Doppler cooling of Barium ions and their use for sympathetically cooling Ytterbium ions [1]. We use a novel planar microstructured segmented linear Paul trap to trap Yb+ and Ba+ ions simultaneously. Two schemes for Electromagnetically Induced Transparency (EIT) cooling tailored to the use in inhomogeneous magnetic fields are investigated, the first one takes advantage of Zeeman sublevels of the S1/2-P1/2 transition, and the second includes sublevels of the D3/2 state in 138Ba+. We showcase the outcomes of numerical simulations for various cooling methods, indicating that ions can achieve mean phonon numbers of 0.9 at rates of a few kHz in the axial mode at 150 kHz secular trap frequency. Furthermore, details of the experimental setup and first measurement results are presented. Specifically, we investigate tailored EIT cooling schemes in the absence and presence of magnetic field gradients. References [1] K. Sosnova, et al., Physical Review A 103, 012610 (2021)

Q 55.17 Thu 17:00 Tent B

Elements for quantum computing with trapped ions using cryogenic electronics — •Rodolfo Munoz-Rodriguez, Dorna Niroomand, Ivan Boldin, Daniel Busch, Patrick Huber, Markus Nünnerich, and Christof Wunderlich — Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany

Coherently controlling internal and motional degrees freedom of trapped ions is a prerequisite for using them for quantum information processing. Scaling up ion traps such that control of a large number of ions becomes possible requires typically excellent vacuum (XHV) and low heating rates of the ions motion, both are achieved in a cryogenic environment. At the same time, electronics generating electro-magnetic fields for ion control should be placed on or near micro-structured traps.

We set up an apparatus for investigating cryogenic (4 K) planar ion traps with electrodes controlled by cryogenic digital-to-analog-converters (DACs). Our trap chip architecture includes elements for creating a static magnetic field gradient which allows the use of radio frequency fields for coherent control. The integrated DACs allow for flexibly shaping the trapping potential for the targeted control and optimization of the interaction between ions for specific gate operations, and transport ions between different trapping zones. The first trap generation will consist of a single layer metallization layer, a single processing zone, 26 DC electrodes and a combination of integrated and external DACs.

Q 55.18 Thu 17:00 Tent B

Double imaging and stray light suppression for a multi species Paul trap for quantum computing — •Ernst Alfred Hackler, Pedram Yaghoubi, Florian Köppen, Hendrik Siebeneich, and Christof Wunderlich — Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany

Multi-species ion crystals are useful, for example, for quantum information processing with trapped ions or for quantum logic spectroscopy. Here, we report on the development and performance of an imaging system for mixed ion crystals of Barium and Ytterbium ions. Since the wavelengths of the resonance fluorescence of these two ion species are far apart (369 nm and 493 nm, respectively), dispersion in a refractive imaging system has to be considered. To image both species simultaneously, a double imaging system was designed and built, taking into account dispersion and chromatic aberrations. At the same time, this set-up efficiently suppresses stray light. In this poster, I present the simulation and measurement results that were used to quantify the performance of this set up.

Q 55.19 Thu 17:00 Tent B

Towards a Quantum Gas Microscope for fermionic NaK molecules — •Leonard Bleiziffer, Shrestha Biswas, Sebastian Eppelt, Xingyan Chen, Christine Frank, Timon Hilker, Immanuel Bloch, and Xinyu Luo — Max Planck Institute for Quantum Optics, Garching, Germany

This poster presents the development of a quantum gas microscope tailored for fermionic sodium-potassium (NaK) molecules in an optical lattice. Our approach involves disassembling the molecules and then applying Raman Sideband cooling to the potassium atoms. This technique will enable the imaging of potassium atoms through the utilization of thousands of scattered photons, ensuring their retention within the lattice despite the heating due to photon recoil. We address the challenges associated with implementing Raman sideband cooling in such a setup, particularly the required Raman-and repumper-beams apparent from the hyperfine fermionic potassium level structure. Also, we describe the plan for a modification of the optical lattice into a deep, bow-tie configuration to reach the Lamb-Dicke regime necessary for Raman Sideband cooling. As a demonstrative example, we want to explore the long-range XY model, which is particularly noteworthy as it can only be simulated in the context of the long-range interactions characteristic of polar molecules, a feat not achievable with standard atomic quantum simulators. We currently work on a tensor-network simulation of the long-range XY model showcasing the dynamics of the global spin-polarization that we later want to compare to the quantum simulation utilizing the new Quantum gas microscope.

Q 55.20 Thu 17:00 Tent B

Non-abelian invariants in periodically-driven quantum rotors — •Volker Karle, Areg Ghazaryan, and Mikhail Lemeshko — Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg

This poster explores the role of topological invariants in the non-equilibrium dynamics of periodically-driven quantum rotors, inspired by experiments on closed-shell diatomic molecules driven by periodic, far-off-resonant laser pulses. This approach uncovers a complex phase space with both localized and delocalized Floquet states. We demonstrate that the localized states are topological in nature, originating from Dirac cones protected by reflection and time-reversal symmetry. These states can be modified through laser strength adjustments, making them observable in current experiments through molecular alignment and observation of rotational level populations. Notably, in scenarios involving higher-order quantum resonances leading to multiple Floquet bands, the topological charges become non-Abelian. This results in the remarkable finding that the exchange of Dirac cones across different bands is non-commutative, enabling non-Abelian braiding, paving the way for the study of controllable multi-band topological physics in gas-phase experiments with small molecules, as well as for classifying dynamical molecular states by their topological invariants.

Q 55.21 Thu 17:00 Tent B

Signatures of many-body localization in a two-dimensional lattice of ultracold polar molecules with disordered filling — •Timothy J. Harris[1,2,3], Andrew J. Groszek[1], Arghavan Safavi-Naini[4,5], and Matthew J. Davis[1] — [1]ARC Centre of Excellence for Engineered Quantum Systems, School of Mathematics and Physics, University of Queensland, Brisbane, QLD 4670, Australia — [2]Department of Physics and Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München, 80333 München, Germany — [3]Munich Center for Quantum Science and Technology, 80799 München, Germany — [4]Institute for Theoretical Physics, Institute of Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, the Netherlands — [5]QuSoft, Science Park 123, 1098 XG Amsterdam, the Netherlands

We present our work exploring many-body localization (MBL) in systems of ultracold polar molecules confined to a two-dimensional (2D) optical lattice with disordered filling. We perform large-scale exact diagonalization simulations to characterize the dynamics and eigenstate properties of the system. We observe several key signatures of MBL as the relative strength of the spin-density interactions is increased, including retention of initial state memory in the system's long-time dynamics, logarithmic growth of bipartite entanglement entropy and a transition to Poissonian level-spacing statistics. Our predictions may be realised in state-of-the-art quantum gas microscope experiments with alkali-metal dimers, and open exciting new avenues to explore non-equilibrium many-body physics with ultracold polar molecules.

Q 55.22 Thu 17:00 Tent B

Evaluation of the potential of PL5-7 centers in 4H-SiC for spin-based quantum sensing — •Raphael Wörnle[1], Jonathan Körber[1], Timo Steidl[1], Georgy Astakhov[2], Florian Kaiser[1,3], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, IQST and Research Centre SCoPE, University of Stuttgart, ZAQ, Stuttgart, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Dresden, Germany — [3]MRT Department, Luxembourg Institute of Science and Technology, Belvaux, Luxembourg

4H-silicon carbide (SiC) has emerged as a promising platform to host point defects with possible applications in quantum technologies, such as distributed quantum computing or sensing. However, the typically detected spin signal contrast of color centers in SiC and the count rates are quite low.

Recently, divacancies located near stacking faults in 4H-SiC (PL5- 7 centers) have drawn considerable attention. They impress with a high readout contrast and a high photon count rate, making them competitive with the NV center in diamond. However, as the defects are relatively new, their theoretical properties are unexplored and their creation is not yet deterministically possible.

Here, we present the generation of PL5-7 centers through ion irradiation and characterize their spin properties via optically detected magnetic resonance (ODMR) and pulsed measurements at room temperature. Further, we show the coupling between a nuclear spin and single defect spins.

Q 55.23 Thu 17:00 Tent B

Computer Simulation Framework for coherent two-dimensional electronic Spectroscopy — •Joel Ströhmann and Mario Agio — Laboratory of Nano Optics, Universität Siegen, Siegen, Germany

2D spectroscopy represents the electric field intensity as a correlation map of two independent variables, e.g. the excitation and emission frequency of a quantum system. This allows the deconvolution of different spectral features along the second axis, in particular the presence of coherent couplings in off-diagonal peaks between the coupled states. My masters project was to summarize the mathematical formulation of the optical response function for an arbitrary pulse trail based on perturbation theory and develop a software framework for the automated computation of the optical response. The system's properties and the pulse shape are provided as external parameters to the software and the numerical simulation is carried out either with full integration over the pulse envelope or in the semi-impulsive limit. In particular, the computation of the optical response of an arbitrary number of two-level systems with arbitrary, lossless pair-wise couplings can be computed automatically including dephasing and population relaxation for each two-level system.

Q 55.24 Thu 17:00 Tent B

Quantum photonics using color centers in a diamond membrane coupled to a photonic structure — •Surena Fatemi[1,2], Aurélie Broussier[2], Roy Konnoth Ancel[2], Jan Fait[3], Christophe Couteau[2], and Christoph Becher[1] — [1]Fachrichtung Physik, Universität des Saarlandes, Campus E2.6, 66123, Saarbrücken, Germany — [2]Light, nanomaterials, nanotechnologies (L2n), EMR CNRS 7004, Université de Technologie de Troyes (UTT) 12 rue Marie Curie, CS 42060, 10004 Troyes cedex, France. —

[3]FZU - Institute of Physics of the Czech Academy of Sciences, Prague

In recent years, color centers of wide band-gap materials have drawn a lot of attention due to their superior properties for quantum technologies. One of the most interesting color center systems are the group-IV color centers in diamond due to their long spin coherence times and excellent optical properties such as narrow optical emission lines, high spectral stability, and bright single-photon emission. However, one of the main obstacles for realization of a quantum device exploiting color centers is the lack of efficient out-coupling of photon emission from the diamond itself which leads to low photon rates. We consider a group-IV color center in a diamond membrane evanescently coupled to photonic waveguides such as Silicon-on-Insulator and Ion-Exchanged glass waveguides. We present design studies and simulations including the membrane geometry, coupling interface, and waveguide structures using Finite-Element-Method simulations and Monte-Carlo optimization to improve the out-coupling of the emission in order to achieve high photon rates.

Q 55.25 Thu 17:00 Tent B

A triggered narrow-band photon number adjustable emitter using organic molecule — •Yijun Wang, Subhabrata Ghosh, Maximilian Luka, and Ilja Gerhardt — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany

We utilize single molecule microscopy under cryogenic conditions as single photon emitters. Our near-sodium-resonance photon emitters' robustness allows for triggered photon emission with a narrow bandwidth and an adjustable photon count. We implement off-resonant excitation on DBATT molecule and detect the near-sodium resonance photons after a Faraday filter. The photons are generated with a "button press" style and are triggered. The single photon purity is well proved by the auto-correlation function. The photon number per "button press" can be adjusted by tuning an external electric field.

Q 55.26 Thu 17:00 Tent B

Organic molecule photon number adjustable quantum emitters — •Yijun Wang, Subhabrata Ghosh, Maximilian Luka, and Ilja Gerhardt — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany

We utilize single molecule microscopy under cryogenic conditions to implement non-classical photon sources. Our near-sodium-resonant photon emitters allow for triggered photon emission with a narrow bandwidth and an adjustable photon number per trigger. We implement off-resonant excitation on DBATT molecules and detect the near-sodium resonant photons behind an atomic vapor filter based on the Faraday effect. The photons are generated in a "press-button" style. Our emitters could behave as very good single photon emitters. The single photon purity is well justified by the low value of $g^{(2)}(0)$. Alternatively, we can adjust the photon number per "press-button" by the DC Stark shift.

Q 55.27 Thu 17:00 Tent B

Organic molecule photon number adjustable quantum emitters — •Yijun Wang, Subhabrata Ghosh, Maximilian Luka, and Ilja Gerhardt — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany

We utilize single molecule microscopy under cryogenic conditions to implement non-classical photon sources. Our near-sodium-resonant photon emitters are based on organic molecules, and allow for triggered photon emission with a narrow bandwidth and an adjustable photon number per trigger. We implement off-resonant excitation on DBATT molecules and detect the near-sodium resonant photons behind an atomic vapor filter based on the Faraday effect. The photons are generated in a "press-button" style. The single photon purity is well justified by the low value of $g^{(2)}(0)$. Alternatively, we can adjust the photon number per trigger by the DC Stark shift.

Q 55.28 Thu 17:00 Tent B

Homogeneous etching of nanofabricated waveguide structures in 4H-SiC for quantum information applications — •Nithin Thomas Alex, Marcel Krumrein, and Jörg Wrachtrup — 3rd Institute of Physics, IQST, and Research Centre SCoPE, University of Stuttgart, Germany

Silicon Carbide (SiC) is a wide bandgap semiconductor used abundantly in high power electronics applications. It has also found its way into the quantum industry as it can host color centers with great spin-optical properties. Integration of these defects into nanophotonic structures, such as waveguides and photonic crystal cavities (PCCs), is key to implement quantum network nodes. Even though the research in this field is making steady progress, proper fabrication techniques for the scalability of these structures still needs to be addressed. The current techniques, such as using a Faraday cage, for fabricating waveguides and PCCs with a triangular cross-section[1] lack homogenous etching on the wafer scale. To overcome these challenges, we have been testing various recipes in the state-of-the-art reactive ion beam etching (RIBE) device from OXFORD instruments, called Ionfab 300+.

[1] S. Majety, V. A. Norman, L. Li, M. Bell, P. Saha, and M. Radulaski, *Quantum photonics in triangular-cross-section nanodevices in silicon carbide,* Journal of Physics: Photonics, vol. 3, p. 34008, 2021.

Q 55.29 Thu 17:00 Tent B

Optimizing Sensing using NV-centers via Spin-to-Charge conversion — •Tobias Feuerbach, Nimba Pandey, Oliver Opaluch, and Elke Neu-Ruffing — Rheinland Pfälzische Technische Universität Kaiserslautern, Fachbereich Physik, Erwin-Schroedinger-Str., Bau 56, Raum 278

Quantum sensing leverages quantum mechanics to achieve unprecedented levels of precision in measuring physical quantities. Nitrogen-vacancy (NV) centers in diamond are among the most promising candidates in this fast-emerging field. They can be used to measure magnetic fields, pressure and temperature, for example. Single NV centers at room temperature have been shown to enable measurement sensitivity in the $\mathrm{nT}/\sqrt{\mathrm{Hz}}$ range and nanoscale resolution at the same time [1]. Despite the versatility and sensitivity of diamond-based sensors, the inherent noise of the readout process restricts their potential. The classical readout relies on spin state dependent fluorescence and thus is limited by photon shot noise. Spin-to-charge conversion (SCC) based methods offer a remedy to this issue and achieve higher readout contrast and better readout fidelity. Previous works have shown a five-fold improvement in the sensitivity using SCC based readout [2]. In this work, we present the basic idea of SCC based readout, and demonstrate the setup design required to enable the method. The primary goal of the work is to utilize SCC based methods to study the host material along with its application for different sensing protocols.

[1] Wrachtrup et al., Phys. Rev. Lett., vol.102, p.057403, Feb 2009.
[2] Walsworth et al., Phys. Rev. Appl., vol.11, p.064003, Jun 2019.

Q 55.30 Thu 17:00 Tent B

Ultrafast single-photon detection at high repetition rates based on optical Kerr gates under focusing — •Amr Farrag[1], Abdul-Hamid Fattah[1], Assegid Mengistu Flatae[1], and Mario Agio[1,2] — [1]Laboratory of Nano-Optics and Cμ, University of Siegen, 57072 Siegen, Germany — [2]National Institute of Optics (INO), National Research Council (CNR), 50125 Florence, Italy

The ultrafast detection of single photons' emitters is currently bound by the limited time resolution (a few picoseconds) of the available single-photon detectors. Optical Kerr gates can offer a faster time resolution, but until now they have been applied to ensembles of emitters. Here, we demonstrate through a semi-analytical model that the ultrafast time-resolved detection of single quantum emitters can be possible using an optical Kerr shutter at GHz rates under focused illumination. This technique provides sub-picosecond time resolution, while keeping a gate efficiency at around 85%.

Q 55.31 Thu 17:00 Tent B

Mobile quantum sensing setup based on Nitrogen-Vacancy centers in diamond — •Wanrong Li[1], Oliver Gerull[1], Mike Johannes[1], Florian Böhm[1], Masazumi Fujiwara[2], and Oliver Benson[1] — [1]Humboldt-Universität, Berlin, Germany — [2]Okayama University, Okayama, Japan

Nitrogen-Vacancy (NV) defect centers in diamonds have exhibited remarkable quantum properties with diverse applications in quantum technology and sensing. Here we introduce a mobile setup designed for efficient quantum sensing such as on-site magnetometry based on the exceptional sensitivity of NVs to magnetic fields at the nanoscale. We measured the Optically Detected Magnetic Resonance (ODMR) [1] spectra of NVs, by sweeping the microwave frequency and monitoring the fluorescence signal. The positions and shapes of the dips in the spectrum provide information about the NV center's electron spin properties, enabling precise measurement for magnetic field variations. The versatility of this setup allows for exploration not only of ensembles of NVs but also at the single NV level. Additionally, the setup enables T2 (spin-spin relaxation time) measurements [2], providing insights into the coherence times of the spin states. Looking ahead, this mobile platform has the potential to serve as a robust tool for conducting sensing in biophysics research, and other studies that strictly required on-site measurements.

References:
[1] M. Fujiwara et al., Phys. Rev. Res. 2, 043415 (2020).
[2] F. Böhm, Ph.D. thesis, Humboldt-Universität zu Berlin (2022).

Q 55.32 Thu 17:00 Tent B

Using low-cost Blu-Ray Optical Pickup Units for Measurement of Single Photon Emission from NV-Centers — •Simon Klug[1], Jonas Homrighausen[1], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, University of Applied Science, Münster, Germany — [2]Department of Electrical Engineering and Comuputer Science, University of Applied Science, Münster, Germany

Color centers in diamonds have proven to be promising quantum emitter candidates for many applications in quantum information and quantum sensing. Not only do they serve as efficient single photon sources at room temperature, but they also enable the analysis of spin dynamics and spin coherence times. Conventional detection approaches using high-NA microscope objectives and intricate piezo positioning systems [1] have turned out to be expensive and sophisticated [2]. In response to these challenges, our setup utilizes Blu-Ray optical pickup units (OPUs) [3] and offers a cost-effective solution to enhance access to single-photon research. These OPUs have built-in aspheric lenses and positioning mechanisms which we utilize to identify emitters and successfully measure single photon emssion from NV nanodiamonds.

[1] B. Rodiek et al., Optica, vol. 4, no. 1, Jan. 2017.
[3] T. Schröder et al., Opt. Express, vol. 20, no. 10, May 2012.
[4] T.-J. Chang et al., Commun. Phys., vol. 4, no. 1, Feb. 2021.

Q 55.33 Thu 17:00 Tent B

Artificial light-harvesting complexes based on silicon-vacancy color centers in diamond. — •Laurin Göb[1,2], Assegid Flatae[1,2], Florian Sledz[1,2], Lukas Strauch[1,2], Joel Ströhmann[1,2], and Mario Agio[1,2] — [1]Laboratory of Nano-Optics, University of Siegen, 57072 Siegen, Germany — [2]Cμ - Research Center of Micro- and Nanochemistry and (Bio)Technology, University of Siegen, 57068 Siegen, Germany

Light-harvesting complexes (LHC) are nanoscale structures found in photosynthetic organisms. They are ring-like structures used to efficiently absorb light and transport quantum excitations to induce chemical processes. Constructing artificial complexes, that mimic these natural phenomena, allow to develop new functional materials for quantum photonics. In this work, we introduce LHC based on silicon-vacancy color-centers in diamond coupled to gold nanostructures and study their photophysics.

Q 55.34 Thu 17:00 Tent B

Surface-supported single organic molecules demonstrate lifetime-limited linewidths — •Ashley Shin[1], Masoud Mirzaei[1,2], Alexey Shkarin[1], Johannes Zirkelbach[1], Jan Renger[1], Tobias Utikal[1], Stephan Götzinger[1,2,3], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander University Erlangen-Nürnberg, 91052 Erlangen, Germany

Polycyclic aromatic hydrocarbons (PAHs) have robust photophysics, synthetic tunablity, and facile handling properties, making them an excellent platform for molecular quantum optics. The PAH molecules are often embedded in crystals to minimize environmental dephasing, which limits non-optical access that otherwise can be useful for nanoprobe technologies or novel nanophotonic designs. In this work, we investigate dibenzoterrylene (DBT) molecules placed on top of pristine anthracene crystals. Despite being at the interface between vacuum and crystal, the DBT molecules demonstrate Fourier-limited linewidths at sub-Kelvin temperatures. The on-surface DBTs emit at higher frequencies and longer lifetimes from their embedded counterparts, while following a similar temperature-dependent dephasing trend. We report via a comprehensive set of fluorescence measurements that desired photophysical properties of DBTs as single quantum emitters are preserved on the surface.

Q 55.35 Thu 17:00 Tent B

Identifying Yellow Color-Centers in Hexagonal Boron-Nitride — •Pablo Tieben[1,2] and Andreas W. Schell[3] — [1]PTB, Bundesallee 100, 38116 Braunschweig, Deutschland — [2]LUH, Inst. f. Festkörperphysik, Appelstrasse 2, 30167 Hannover, Deutschland — [3]JKU, Inst. f. Halbleiter und Festkörperphysik, Altenberger Str. 69, 4040 Linz, Österreich

Single photon emitters are an essential resource for the rapidly developing field of quantum technologies. Color centers in hexagonal boron nitride (hBN) pose a suitable system for single photon generation due to their bright and stable photon emission at room temperature. Due to the large bandgap of the material a plethora of emitters across the visible and near-infrared spectrum have been discovered. Some emitters exhibit intricate level structures with the possibility for advanced optical control. Recently the origin of emitters in the yellow spectral region have been tied to carbon related defects, but the exact atomic composition remains elusive. Based on previously found connections between the emission and excitation characteristics of these emitters, we perform additional spectroscopic measurements under simultaneous excitation with multiple wavelengths. We analyze the emission spectrum, photon flux and temporal emission stability as well as the second-order autocorrelation for fixed primary and varying secondary excitation wavelength. The dependency of these properties on the secondary wavelength can reveal additional information about the underlying level structure. Paired with theoretical predictions for different carbon defects the atomic origin can be narrowed down even further.

Q 55.36 Thu 17:00 Tent B

SiV centers in nanodiamonds for quantum networks — •Richard Waltrich[1], Marco Klotz[1], Andreas Tangemann[1], Lukas Antoniuk[1], Niklas Lettner[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik Universitat Ulm — [2]Universite Francois Rabelais de Tours

The realization of a quantum network is of great interest. The combination of the good optical and spin properties of group IV defects in diamond with established technologies such as photonic structures brings the realization of a quantum network node within reach. We present measurements of characteristic properties of SiV centers in nanodiamonds compared to bulk diamond, showing key features for the realization of a quantum network node such as improved coherence times, spin control, and indistinguishable photons.

Q 55.37 Thu 17:00 Tent B

towards coherent dipole-dipole coupling: cryogenic single-molecule microscopy of dbatt dimers — •Siwei Luo[1,2], Michael Becker[1], Hisham Mazal[1], Alexey Sharkin[1], Aleksandr Oschepkov[3], Konstantin Amsharov[3], Tim Hebenstreit[1,2], Jan Renger[2,1], Vahid Sandoghdar[1], and Stephan Götzinger[1,2] — [1]Max Planck Insitute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany — [3]Insitute of Chemistry, Martin Luther University Halle Wittenberg, Halle, Germany

Coherently coupled molecules are an interesting resource for quantum optics and quantum information processing, providing access to sub- and superradiant decay paths. Such pairs of molecules have only been found in the past by brute force methods, since molecules are usually randomly doped into the host matrix and high doping levels cannot be tolerated. To address this longstanding issue, our new approach is based on recent developments in organic chemistry where an organic linker with a known length of less than 2nm can connect two fused 2D acene emitters. Here we will present cryogenic single-molecule spectroscopy and localization microscopy studies on 2,3,8,9-dibenzanthanthrene (DBATT) dimers. By embedding these dimers in shock-frozen tetradecane matrices, they clearly demonstrate lifetime-limited linewidths and similar fluorescence spectra as single DBATT molecules. Our results are a first step towards a routine investigation of cooperative phenomena using molecular dimers.

Q 55.38 Thu 17:00 Tent B

Utilizing Integrated Single Photon Emitters on Waveguides for Testing Extended Quantum Theories — •Josefine Krause[1], Mohammad Nasimuzzaman Mishuk[1], Kabilan Sripathy[1], Najme Ahmadi[1], Sebastian Ritter[1], Mostafa Abasifard[1], Giacomo Corielli[3], and Tobias Vogl[1,2] — [1]Friedrich Schiller University Jena, Institute of Applied Physics, Albert-Einstein-Straße 15, 07745 Jena — [2]Technical University of Munich, TUM

School of Computation, Information and Technology, Arcisstraße 21, 80333 München — [3]Consiglio Nazionale delle Ricerche (IFN-CNR), Istituto di Fotonica e Nanotecnologie, Piazza Leonardo da Vinci 32, 20133 Milano, Italy

Efficient utilization of quantum information processing, for example for satellite-based quantum communication, relies on the miniaturization and combination of components into compact, space-compatible structures. For this, we follow the hybrid approach of integrating quantum emitters hosted in two-dimensional materials onto a photonic chip containing femtosecond laser-written waveguides. The single photon source (SPS), which is a fluorescent defect in hexagonal boron nitride, operates at room temperature and has potential to outperform laser-based decoy quantum key distribution protocols with a higher data rate. The waveguides form a tunable three-path interferometer that offers to test the boundary of a fundamental postulate of quantum physics, being Born's rule, by measuring higher order interferences. Both this, and the purity of the SPS will be tested on a 3U CubeSat in microgravity as part of the QUICK3 mission.

Q 55.39 Thu 17:00 Tent B

Spin Properties of SiV Center in Nanodiamonds — •Kathrin Schwer[1], Marco Klotz[1], Andreas Tangemann[1], Richard Waltrich[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik Universität Ulm — [2]Universite Francois Rabelais de Tours

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

Q 55.40 Thu 17:00 Tent B

Investigating exciton-plasmon interaction in an ion-exchanged glass covered by silver iodide nanoparticles — •Razieh Talebi — Department of Physics, University of Isfahan, 81747-73441 Isfahan, Iran — Department of Physics, University of Isfahan, 81747-73441 Isfahan, Iran

Silver nanoparticles embedded in dielectric or semiconductor films have attractive optical properties that make these materials to be used as plasmonic sensors and waveguides. The silver ions are doped in a thin layer of glass under ion-exchange process. Subsequently, the silver nanoparticles can form in this layer by post-annealing treatment which is tracked by in-situ XRD pattern. The exciton of semiconductors such as silver iodide can interact with the localized surface plasmon resonance of silver nanoparticles. The exciton-plasmon interaction in an ion-exchanged glass covered with silver iodide is investigated by absorption spectra at room temperature. The spectra of these materials before and after silver iodide nanoparticles are exposed, are compared.

Q 55.41 Thu 17:00 Tent B

Fluorescence resonance energy transfer near plasmonic nanostructures — •Shubhadeep Mondal and Markus Lippitz — University of Bayreuth

Fluorescence resonance energy transfer (FRET) plays a key role in photosynthesis, photovoltaics, biosensing, light sources, and more. It describes the nanoscale energy transfer between fluorophores, taking into account the near-field non-radiative dipole-dipole (donor-acceptor) interaction. Our goal is to study the coupling between quantum emitters and the influence of the nanoscale environment on it, for which it is crucial to design a photonic environment to control the FRET rate and efficiency. FRET can be measured by its influence on donor lifetime and acceptor brightness, but the plasmonic environment also modifies both signals by the Purcell effect and fluorescence quenching. We will discuss our experimental setup and data analysis to disentangle these effects.

Q 55.42 Thu 17:00 Tent B

Metal-enhanced photosensitization in riboflavin functionalized gold nanoparticles: photophysical mechanisms and application in bioimaging — •Jelena Pajovic[1], Radovan Dojcilovic[2], Dragana Tosic[2], Matthieu Refregiers[3], Dusan Bozanic[2], and Vladimir Vladimir[2] — [1]Faculty of Physics, University of Belgrade, Belgrade, Serbia — [2]Vinca Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, Belgrade, Serbia — [3]Centre de Biophysique Moleculaire, Orleans, France

Photodynamic therapy relies on the photogeneration of reactive oxygen species in complex environments by photosensitizing (PS) molecules. However, challenges persist in enhancing the PS processes while decreasing the concentration of the agents employed. This study explores the integration of PS biomolecules onto plasmonic nanoplatforms to increase their efficiency. Specifically, we report on the influence of gold nanoparticles on the PS activity of riboflavin molecules. The physical characterization of riboflavin-functionalized gold nanoparticles was conducted to better understand their electronic interactions that lead to enhanced singlet oxygen generation. The effects of the functionalized nanoparticles on live bacteria and hepatocellular carcinoma cells were investigated by fluorescence bioimaging. Preliminary findings indicate higher cell death rates in both organism systems, suggesting the nanoparticles' potential as efficient PS agents.

Q 55.43 Thu 17:00 Tent B

Nonlinear emission properties of inverted plasmonic nanostructures — •Valentin Dichtl, Thorsten Schumacher, and Markus Lippitz — Experimental Physics III, University of Bayreuth

The nonlinear third-order material response of noble metals allows the shaping of the third-harmonic near-field around a plasmonic nanostructure [1]. The corresponding spatial emission pattern of the third-harmonic hot spots changes drastically when the fundamental wavelength is slightly tuned by a linear resonance of the nanorod.
However, third harmonic generation (THG) also leads to high temperatures in the structure and its surroundings. These temperatures tend to be high enough to destroy more complex samples. Therefore, structures with the same emission characteristics but a higher ratio of THG to temperature are needed.
To overcome this, we are inspired by Babinet's principle. In this sense, a rod antenna can be replaced by a slit in a thin gold film. The surrounding gold should now be more effective in diffusing heat than a single rod. This poster compares the (nonlinear) emission properties of plasmonic nanostructures and their complementary counterparts.

[1] Wolf, D. *et al.* Shaping the nonlinear near field. *Nat. Commun.* 7:10361 (2016). doi: 10.1038/ncomms10361

Q 55.44 Thu 17:00 Tent B

Optical Interferometry for precise phase measurement — •Dahi Ibrahim — Engineering and Surface Metrology Lab., National Institute of Standards, Tersa St., El haram, El Giza, Egypt

Precision measurements are important across all fields of science. Optical phase measurements which can be used to measure distance, position, displacement, acceleration, and optical path length are of particular interest. In this research, we have demonstrated an optical phase measurement using a polarization interference microscope with temporal stability down to 1.3 nm for one hour. The microscope is based on the measurement of the Stokes parameters S2 and S3. The Stokes parameters describe the polarized light incident to the camera. The microscope was used to calibrate a groove structure of 60 nm nominally. The axial and lateral measurements of the groove structure are presented. The axial depth measurement is performed based on the ISO 5436 profile analysis. Since the ISO 5436 profile analysis doesn't provide a direct measurement of the lateral step height/depth standards, a Hamming area model is proposed to perform this task. For the axial measurement, the computed results show that the depth of the groove structure is 59.7 +- 0.6 nm. For the lateral measurement, the computed results show that the difference between the two line edges of the groove structure is 151.7 +- 2.5 nm. The results lead the way to new high-precision measurement applications.

Q 55.45 Thu 17:00 Tent B

Optical properties of biosynthesized nanoscaled Eu2O3 for red luminescence and potential antidiabetic applications — •Hamza Mohamed — UNISA, Cape Town, South Africa

This contribution reports on the optical properties of biosynthesised Eu2O3 nanoparticles bioengineered for the first time by a green and cost effective method using aqueous fruit extracts of Hyphaene thebaica as an effective chelating and capping agent. The morphological, structural, and optical properties of the samples annealed at 500*C were confirmed by using a high-resolution transmission electron microscope (HR-TEM), x-ray diffrac tion analysis (XRD), UV*Vis spectrocopy, and photoluminescence spectrometer. The XRD results confirmed the characteristic body-centered cubic (bcc) structure of Eu2O3 nanoparticles with an average size of 20 nm. HRTEM revealed square type morphology with an average size of *6 nm. Electron dispersion energy dispersive x-ray spectroscopy spectrum confirmed the elemental single phase nature of pure Eu2O3. Furthuremore, the Fourier transformed infrared spectroscopy revealed the intrinsic characteristic peaks of Eu*O bond stretching vibrations. UV*Vis reflectance proved that Eu2O3 absorbs in a wide range of the solar spectrum from the VUV*UV region with a bandgap of 5.1 eV. The luminescence properties of such cubic structures were characterized by an intense red emission centered at 614 nm. It was observed that the biosynthesized Eu2O3 nanoparticles exhibit an efficient red-luminescence and hence a potential material as red phosphor.

Q 55.46 Thu 17:00 Tent B

Single mode coupled emission of cw and resonant excited GaAs quantum dots — •Martin Kernbach[1], Sophia Fuchs[2], Julian Siller[2], and Andreas W. Schell[1] — [1]Johannes Kepler University Linz — [2]Leibniz University Hannover

Advanced quantum technologies like computing or sensing demand for deterministic bright sources of single indistinguishable photons. In order to provide quantum light of isolated systems properly usable for quantum applications, an efficient excitation and extensive collection in a single mode is required. Single molecules and cavity confined quantum dots are convenient sources. The coupling to the excited state is maximized on resonance, but challenges the usability of the emitter due to the effort for separation of the optical excitation mode from the mode of emission. A temporal, spacial, spectral, or combined method for separation is typically used.

Here we present a realization of a single emitter under resonant excitation in a confocal setup with a polarization filtered emission coupled into a single mode fiber. The optical path is free beam along a one meter long stick which dives the objective lens and scanning stage into a liquid helium reservoir. For resonant cw excitation of GaAs semiconductor quantum dots a SNR of polarization suppression up to 400 and count rates of 2 Mcps are archived by using a collecting lens with NA 0.68 only. Under this scheme further investigations regarding the blinking behavior are possible as well as probing alternative emitters like single molecules.

Q 55.47 Thu 17:00 Tent B

Squeezed States for Gaussian Boson Sampling From a KTP Waveguide Resonator — •Jonas Sichler, Christine Silberhorn, and Michael Stefszky — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Gaussian boson sampling (GBS) stands at the forefront of quantum computational research, offering the possibility of demonstrating quantum computational advantage and may also be suitable for solving complex problems beyond the reach of classical computers. The generation of suitable squeezed states is essential in harnessing the quantum advantages of this architecture, but is a technically challenging feat.

Here, we investigate the possibility of producing the required single-spectral mode, single-mode squeezed states using a resonator assisted type 0 parametric down-conversion (PDC) process in KTP waveguides. We present our findings on cavity parameter optimisation and initial experimental results.

Q 56: Poster VII

Time: Thursday 17:00–19:00 Location: KG I Foyer

Q 56.1 Thu 17:00 KG I Foyer

High-order harmonic generation in gases with μJ laser pulses — •Matthias Meier[1], Philip Dienstbier[1], Yuya Morimoto[2], Francesco Tani[3], and Peter Hommelhoff[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]RIKEN Cluster for Pioneering Research (CPR), RIKEN Center for Advanced Photonics (RAP), Japan — [3]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

Applying strong few-cycle pulses in the infrared together with attosecond pulses in the ultraviolet regime in a pump-probe scheme provides a mighty tool for spectroscopy of ultrafast electron dynamics. In order to improve statistics as well as signal-to-noise ratio while keeping the measurement time to a minimum, high repetition rates are desirable. Here, we present a laser system operating at 1 MHz which delivers near infrared 8 fs pulses with an energy of 10 μJ. These pulses drive the process of high-order harmonic generation in an adjacent vacuum chamber where the pulses can furthermore be characterized. The infrared pulses are obtained from shortening 210 fs pulses of an Ytterbium laser amplifier with stable carrier-envelope phase by means of a two-stage compressor based on two argon-filled hollow-core photonic crystal fibers.

Q 56.2 Thu 17:00 KG I Foyer

Influence of molecular properties on matter-wave interferometry — •Lukas Martinetz[1], Benjamin A. Stickler[2], Ksenija Simonović[3], Richard Ferstl[3], Markus Arndt[3], and Klaus Hornberger[1] — [1]University of Duisburg-Essen, Germany — [2]Ulm University, Germany — [3]University of Vienna, Austria

Matter-wave interferometers served to confirm the wave-particle duality with large molecules [1] and enabled to prepare highly delocalized quantum states with molecules of ever increasing mass [2]. Since the internal molecular dynamics can play a decisive role in the interaction with the diffraction grating, matter-wave interferometers hold out the prospects of being sensitive probes for molecular properties. Here, we quantify the impact of these properties by calculating the interference pattern of molecules that are diffracted at a standing laser wave. The interaction with the laser enters through the Talbot coefficients, which incorporate state-dependent polarizabilities and photon-absorption cross sections, and the depletion of the molecular beam through ionization or cleavage. Furthermore, our calculation accounts for the finite size of the particle source and collimation slits, for a distribution of initial particle velocities, as well as for gravity, the Coriolis force and an asymmetric standing laser wave due to non-ideal retroreflection at the grating mirror. We display and discuss features of the pattern for the different molecular processes and compare our model with recent experiments aiming at measuring molecular parameters.

[1] M. Arndt et al., Nature 401, 680 (1999)
[2] Y. Y. Fein et al., Nat. Phys. 15, 1242 (2019)

Q 56.3 Thu 17:00 KG I Foyer

Tunable Bragg-diffraction beam splitters for molecular matter waves — •Eric van den Bosch[1], Benjamin A. Stickler[2], Lukas Martinetz[1], and Klaus Hornberger[1] — [1]University of Duisburg-Essen, Germany — [2]Ulm University, Germany

Matter-wave interferometry offers rich applications ranging from testing fundamental principles of quantum mechanics with large particles to probing material properties and measuring accelerations with high precision. The lack of brilliant sources for heavy particles requires efficient ways to split an incident wave packets into two branches. One way to achieve such large momentum beam splitters is Bragg diffraction at thick optical gratings, as realised experimentally in [1].

We study how further modulations of the laser grating, e.g. adiabatic application of an additional constant force, may extend established means to control populations in the interferometer arms [2], as well as provide a first step towards Bragg diffraction at thin gratings.

[1] Brand, Kiałka, Troyer, Knobloch, Simonović, Stickler, Hornberger, Arndt (2020). Bragg diffraction of large organic molecules. Physical Review Letters, 125(3) [2] Siemß, Fitzek, Abend, Rasel, Gaaloul, Hammerer (2020). Analytic theory for Bragg atom interferometry based on the adiabatic theorem. Physical Review A, 102(3)

Q 56.4 Thu 17:00 KG I Foyer

Atom interferometry with ultra-cold atoms in microgravity — •Anurag Bhadane[1], Julia Pahl[2], Dorthe Leopoldt[3], Sven Abend[3], Ernst M. Rasel[3], Markus Krutzik[2,5], Sven Herrmann[4], Andre Wenzlawski[1], Patrick Windpassinger[1], and The QUANTUS Team[1,2,3,4,6,7] — [1]JGU Mainz — [2]HU Berlin — [3]LU Hannover — [4]U Bremen — [5]FBH Berlin — [6]U Ulm — [7]TU Darmstadt

QUANTUS-2 is a mobile, robust, high flux ^{87}Rb atom interferometry device that can operate in the microgravity environment provided by the drop tower and Gravitower located in Bremen and act as a pathfinder for future space missions. QUANTUS-2 exploits a magnetic lens enhanced by the quadrupole field of the atom chip which enables longer coherence times under microgravity to perform atom interferometery over one second with double Bragg diffraction.

Here, we present the latest results on atom interferometry on extended time scales in the drop tower and initial experiments in the Gravitower.

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

Q 56.5 Thu 17:00 KG I Foyer

Generating auto-ponderomotive potentials using flat, chip-based electrodes for shaping electron beams — •Franz Schmidt-Kaler, Michael Seidling, Robert Zimmermann, Nils Bode, Fabian Bammes, Lars Radtke, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Manipulating free electron beams has been realized with complex electrostatic fields generated with planar electrodes. Within the frame of the moving electron, these static fields transform into an alternating auto-ponderomotive potential, resembling the one of a microwave-driven Paul trap confining the electrons. Prior, we showed that we can split and guide electron beams along curved paths this way, with electron energies ranging from a few electron volts to 1.7 keV (for splitting) and 9.5 keV (for guiding). Here we focus on electron beam resonators. We have demonstrated the first linear version to work for 50 eV electrons and measured its coupling efficiency. All configurations can be integrated into standard SEM*s, offering entirely new options for future coherent electron control. Interaction-free measurement schemes based on repeated electron sample interaction could benefit greatly.

Q 56.6 Thu 17:00 KG I Foyer

Characterization of auto-ponderomotive electron guides — •Nils Bode, Franz Schmidt-Kaler, Fabian Bammes, Lars Radtke, Michael Seidling, Robert Zimmermann, and Peter Hommelhoff — Physik Department, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen

Advanced control over electron beams may enable new coherent electron applications such as a quantum electron microscope. With the help of auto-ponderomotive structures, we have recently demonstrated electron guiding with energies ranging from 20eV to 9,5keV. These electron guides utilize patterned electrostatic electrode assemblies, which, seen from the comoving frame of the electron, generate a pseudopotential similar to conventional Paul traps. We investigate the stability regions of these new 2D traps as well as the coupling efficiencies, both numerically and in experiment, for beam energies between 50eV and 500eV. Additionally, the interim deceleration of electrons inside the guiding potential down to energies of about 0.1eV was simulated. Initial preliminary measurements show a successful deceleration of 40% for an 500eV electron beam.

Q 56.7 Thu 17:00 KG I Foyer

Demonstration of a well-controlled atomic source for Very Long Baseline Atom Interferometry — •Dorothee Tell, Vishu Gupta, Kai Grensemann, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The sensitivity of an atom interferometer measuring the acceleration of a freely falling atomic ensemble can be increased by scaling up the available free fall time. At the Hannover Very Long Baseline Atom Interferometry (VLBAI) facility, we have set up a 10 m long baseline for fountain interferometry with up to 2.4 s of free fall. This promises highly accurate measurements of gravitational accelerations for gravimetry, but also offers several possibilities to test fundamental physics, e. g. at the interface of quantum mechanics and general relativity. However a high level of control over all systematic effects and noise sources is necessary.

This contribution focuses on the source of rubidium Bose-Einstein condensates recently installed in the facility to complete the setup. We demonstrate how the strict constraints necessary for the operation of a highly accurate inertial sensor can be realized. This comprises a fast all-optical evaporation sequence, flexible methods for manipulating the atoms in a time-averaged optical dipole trap e. g. for reducing the expansion speed during free fall, and methods for a well-controlled, efficient launch of the atoms into the baseline based on an accelerated Bloch lattice.

Q 56.8 Thu 17:00 KG I Foyer

Atomic diffraction from single-photon transitions in gravity and Standard-Model extensions — •Alexander Bott[1], Fabio Di Pumpo[1], and Enno Giese[2,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [2]Technische Universität Darmstadt, Fachbereich Physik, Institut für Angewandte Physik, Schlossgartenstr. 7, D-64289 Darmstadt, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

Single-photon transitions are one of the key technologies for designing and operating very-long-baseline atom interferometers tailored for terrestrial gravitational-wave and dark-matter detection. Since such setups aim at the detection of relativistic and beyond-Standard-Model physics, the analysis of interferometric phases as well as of atomic diffraction must be performed to this precision and including these effects. In contrast, most treatments focused on idealized diffraction so far. In this contribution, we study single-photon transitions, both magnetically-induced and direct ones, in gravity and Standard-Model extensions modeling dark matter as well as Einstein-equivalence-principle violations. We take into account relativistic effects like the coupling of internal to center-of-mass degrees of freedom, induced by the mass defect, as well as the gravitational redshift of the diffracting light pulse. To this end, we also include chirping of the light pulse required by terrestrial setups, as well as its associated modified momentum transfer for single-photon transitions.

Q 56.9 Thu 17:00 KG I Foyer

Atom interferometers in weakly curved spacetimes: Case study of the VLBAI — •Michael Werner and Klemens Hammerer — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We present a systematic approach to determine all relevant phases in the VLBAI (Very Long Baseline Atom Interferometer) experiment in Hannover, including (general-) relativistic effects and certain noise sources. Through this approach, we automate the derivation of algebraic expressions for all relevant phases and analyze the impact of mitigation strategies, spanning from the Coriolis effect to gravity gradients. Our objective is to enhance the precision of experiments performed in the VLBAI facility and deepen our understanding of the physics inside such a large scale setup for the detection of relativistic effects.

Q 56.10 Thu 17:00 KG I Foyer

Analytical theory of double Bragg atom interferometers — •Rui Li[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Leibniz University Hanover, Institute for quantum optics, Hannover, Germany — [2]Leibniz University Hanover, Institute for theoretical physics, Hannover, Germany

In this talk, we will provide some new physical insights into a commonly used tool in atom interferometry, namely the double Bragg diffraction (DBD). After reviewing the traditional treatment of DBD with rotating wave approximations and its limitations, we derive an effective two-level-system (TLS) Hamiltonian via Magnus expansion for describing the so-called *quasi-Bragg regime* where most light-pulse atom interferometers are operating. With this effective TLS Hamiltonian, we systematically study the effects of polarization error and AC-Stark shift due to second-order process on the efficiency of double-Bragg beam-splitters. Furthermore, we show that effects of Doppler broadening can be easily included by extending our TLS description to a three-level-system description. Finally, we design an optimal beam-splitter based on our effective theory via a time-dependent detuning and show its robustness against polarization error and asymmetric beam-splitting due to Doppler effect.

Q 56.11 Thu 17:00 KG I Foyer

Phase and error estimation of differential atom interferometry experiments on the ISS — •David B. Reinhardt[1], Nicholas P. Bigelow[2], Matthias Meister[1], and the CUAS team[1,2,3,4] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA — [3]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQST, Ulm University, Ulm, Germany — [4]Leibniz University Hannover, Institute of Quantum Optics, QUESTLeibniz Research School, Hanover, Germany

Matter-wave interferometers in space are excellent tools for high precision measurements, relativistic geodesy, or Earth observation. In differential interferometric setups common-mode noise can be suppresed and the differential phase enables the determination of magnetic field curvatures or gravity gradients. Precise estimation of the differential phase is therefore key as its error contributes significantly to the uncertainty of the whole measurement. If the ignorance about noise types is high and the number of measurements points is small the error estimation becomes severely more challenging. To tackle these issues, we present an improved ellipse fitting method for the estimation of phase, contrast, and population offset of differential interferometers as well as their errors using a modified least-square algorithm combined with bootstrapping of experimental data. Finally, we apply our new method to recent data from the CAL mission measuring magnetic field curvatures on the International Space Station.

Q 56.12 Thu 17:00 KG I Foyer

Quantum-clock interferometry — •Mario Montero[1], Ali Lezeik[1], Klaus Zipfel[1], Ernst M. Rasel[1], Christian Schubert[1,2], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik

The Equivalence Principle assumes the Universality of Gravitational Redshift (UGR), which asserts that the ticking rate of two idealized clocks in a gravitational field is independent of their internal composition. High-precision UGR tests confirm General Relativity's validity but hold the potential to reveal new physics if deviations are found. Quantum-Clock Interferometry (QCI) offers a UGR test based on specific interferometer geometries with delocalised optical clock states to measure differences in proper time affecting the interferometer's phase [1]. We propose an interferometer geometry sensitive to gravitational redshift that benefits from a common-mode rejection of noise effects.

The feasibility of QCI experiments measuring gravitational redshift depends on the availability of long-lived internal states with large energy difference, making the Yb optical clock transition an ideal candidate. We report on the status of our high-flux source of cooled Yb atoms [2]. The optical transition will be driven by a two-photon E1-M1 Doppler-free excitation, requiring a narrow linewidth and high power light source [3]. Here we present our ultra narrow clock laser at 1156 nm with high powers in excess of 20 W.

[1] PRX QUANTUM 2, 040333 (2023). [2] J. Phys. B: At. Mol. Opt. Phys. 54, 035301 (2021). [3] Phys. Rev. A 90, 012523 (2014).

Q 56.13 Thu 17:00 KG I Foyer

Multi-axis quantum gyroscope with multi loop atomic Sagnac interferometry — •Polina Shelingovskaia[1], Ann Sabu[1], Yueyang Zou[1], Mouine Abidi[1], Philipp Barbey[1], Ashwin Rajagopalan[1], Christian Schubert[2], Matthias Gersemann[1], Dennis Schlippert[1], Ernst M. Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt,

Twin-lattice atom interferometers promise high-sensitivity rotation measurements. Our objective is to create a transportable multi-axis gyroscope.

This poster will present the technique of a multi-loop atom interferometer scheme that combines large momentum transfer with the possibility to increase the available free fall time.The focus is on the ongoing progress in the construction of the sensor head using BECs of ^{87}Rb atoms. The associated schematic and the realisation of the necessary laser system for cooling and manipulation are also highlighted.

We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and from DLR with funds provided by the BMWi under grant no. DLR 50NA2106 (QGyro+).

Q 56.14 Thu 17:00 KG I Foyer

Operating an atom interferometer in a vibrationally noisy environment — •Ashwin Rajagopalan, Ernst M. Rasel, Sven Abend, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik,
Welfengarten 1, 30167 Hannover, Germany

Quantum inertial sensing with atom interferometry is a promising tool for reliable and long term stable measurements of inertial effects. Due to its limited dynamic range and reciprocal response the challenge lies in being able to operate an atom interferometer (AI) in a high vibrational noise environment. We have demonstrated operating a T = 10 ms AI without any vibration isolation with the help of a compact opto-mechanical accelerometer. The accelerometer signal was used to suppress the effects of ambient ground vibrational noise coupling into our AI. The coupled noise with a Gaussian full width half maximum of 3.2 mm/s^2 obscures the AI fringes. With our approach, we were not only able to resolve AI fringes and remove measurement ambiguity, but could also measure at a level which is 8 times more sensitive than the ambient vibrational noise that the AI experiences. The new improved version of the opto-mechanical accelerometer has the potential for high precision AI and accelerometer correlation as they share the same inertial reference. We report on the preliminary results and discuss prospects for AI hybridization suitable for dynamic environments.

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Q 56.15 Thu 17:00 KG I Foyer

Artificial Intelligence for Quantum Sensing — •Victor Jose Martinez Lahuerta, Jan-Niclas Kirsten-Siemss, and Naceur Gaaloul — Leibniz University Hannover, Institut of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany

Algorithms from the field of artificial intelligence (AI) and machine learning have been employed in recent years for a variety of applications to efficiently solve multidimensional problems. In physics, these algorithms are applied with increasing success, for example, to solve the Schrödinger equation for many-body problems, or used experimentally to generate ultracold atoms and control lasers. In this project we aim to work on three fundamental pillars of AI in atom interferometry: theory modeling, measurement data extraction, and operation of experiments. Within this context, I will show our results modeling a diffraction phase-free Bragg atom interferometry.

Acknowledgements: This project is funded by the German Space Agency (DLR) with funds provided by the German Federal Ministry of Economic Affairs and Energy (German Federal Ministry of Education and Research (BMBF)) due to an enactment of the German Bundestag under Grant No. DLR 50WM2253A

Q 56.16 Thu 17:00 KG I Foyer

Dark Energy search using atom interferometry in microgravity — •Sukhjovan Singh Gill[1], Magdalena Misslisch[1], Charles Garcion[1], Ioannis Papadakis[2], Baptist Piest[1], Vladimir Schkolnik[2], Sheng-Wey Chiow[3], Nan Yu[3], and Ernst Maria Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany 30167 — [2]Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany 12489 — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA 91109

The nature of Dark energy is one of the biggest quests of modern physics. It is needed to explain the accelerated expansion of the universe. In the chameleon theory, a hypothetical scalar field is proposed, which might affect small test masses like dilute atomic gases. In the vicinity of bulk masses, the chameleon field is hidden due to a screening effect making the model in concordance with observations. Dark Energy Search using Interferometry in the Einstein-Elevator(DESIRE) studies the chameleon field model for dark energy using Bose-Einstein Condensate of ^{87}Rb atoms as a source in a microgravity environment. The Einstein-Elevator provides 4 seconds of microgravity time for multi-loop atom interferometry to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity. This method suppresses the influence of vibrations, gravity gradients and rotations via common mode rejection. The specially designed test mass suppresses gravitational effects from self-mass and its environment. This work will further constrain thin-shell models for dark energy by several orders of magnitude.

Q 56.17 Thu 17:00 KG I Foyer

Absolute light-shift compensated laser system for a twin-lattice atom interferometry — •Mikhail Cheredinov[1], Matthias Gersemann[1], Ekim T. Hanimeli[2], Simon Kanthak[3], Sven Abend[1], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Twin-lattice atom interferometry (AI) is a method for forming symmetric interferometers with matter waves of large relative momentum spitting by using two counter-propagating optical lattices. It has a prospect of enabling highly sensitive inertial measurements.

A limiting factor for large momentum transfer is the loss of contrast, associated with the differential absolute light shift of far detuned light fields, linked to light fields imperfections. Thanks to a flat-top shaped beam and addition of an oppositely detuned light field, this limitation can be mitigated, and new records in momentum separation can be achieved. This contribution presents the realization of a high power laser system for absolute light shift compensated twin-lattice AI with a monolithically mounted flat-top beam shaper.

We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and from DLR with funds provided by the BMWi under grant no. DLR 50WM2250 (QUANTUS+).

Q 56.18 Thu 17:00 KG I Foyer

Squeezing-enhanced Bragg guided BEC interferometry — •Matthew Glaysher[1], Robin Corgier[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, France

Atom interferometers test fundamental theories and have practical applications such as gravimeters, gradiometers and gyroscopes. Using uncorrelated or classically correlated atomic probes state-of-the-art devices already operate at the standard quantum limit (SQL) set by their finite baseline and/or atom number resources.

To push the boundaries of compact devices, we study the realisation of a a Bose-Einstein condensate (BEC) guided interferometer based on Bragg diffraction [R. Corgier et al., PRA, 103 (2021)]. Taking advantage of the BEC oscillations in the waveguide and the possibility to tune atom-atom interactions we investigate the generation of spin-squeezing dynamics between the two modes in well-defined and well-controlled momentum states. The entangled input state feeds a second interferometer sequence with quantum-enhanced sensitivity capabilities. Realistic aspects of the state-preparation parameters, including diffraction efficiencies and BEC collisions and deformations, are addressed in our scheme.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding organisation DFG (project number 499225223).

Q 56.19 Thu 17:00 KG I Foyer

Three-dimensional absorption detection system in the transportable Quantum Gravimeter QG-1 — •Najwa Sophie Al-Zaki[1], Pablo Nuñez von Voigt[1], Nina Heine[1], Waldemar Herr[2], Christian Schubert[2], Ludger Timmen[3], Jürgen Müller[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik, Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The transportable Quantum Gravimeter QG-1 is designed to determine local gravity to the low nm/s^2 level of uncertainty. The installation of two additional absorption detection systems allows the extension of the interferometer separation time 2T. The consecutive detection of the atomic ensemble in two directions enables reconstruction of their three-dimensional position and size, offering new tools for investigating limiting sources of error. This work focuses on estimating the uncertainty of the bias acceleration due to the Coriolis effect by analyzing the reconstructed three-dimensional trajectory.

We acknowledge financial funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 56.20 Thu 17:00 KG I Foyer

Noise Description in Bragg Atom Interferometer Using Squeezed States — •Julian Günther[1,2], Jan-Niclas Kirsten-Siemss[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Hannover, Germany — [2]Institut für Quantenoptik, Hannover, Germany

Using entanglement for N-particle states in matter wave interferometers allows one to outperform the standard quantum limit of $\frac{1}{\sqrt{N}}$ for the uncertainty in the phase measurement. We consider the use of one-axis twisted, spin squeezed atomic states in a Bragg Mach-Zehnder interferometer. We evaluate the phase uncertainty in the phase measurement taking into account the fundamental multi-port and multi-path nature of the Bragg processes, and determine optimally squeezed states for a given geometry.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding organisation DFG (project number 499225223).

Q 56.21 Thu 17:00 KG I Foyer

Towards a three axes hybrid quantum inertial sensor for navigation — •David Latorre Bastidas[1], Dennis Knoop[2], André Wenzlawski[1], Jens Grosse[2], Sven Herrmann[2], and Patrick Windpassinger[1] — [1]Institute of Physics, JGU Mainz — [2]ZARM, University of Bremen

Hybrid quantum inertial sensors based on cold atom interferometry have been proposed as a more accurate alternative for tracking acceleration, e.g. for inertial navigation, compared to current classical accelerometers. In such hybrid sensors, the atom interferometer is used to correct the drift of the classical sensor. Furthermore, the hybridization of both sensors allows for a higher repetition rate and dynamic range compared to pure quantum atom interferometers. In this project, we plan to build a combination of an atom interferometer based on stimulated Raman transitions in a Mach-Zehnder configuration using Rubidium-87 with opto-mechanical sensors, where the acceleration is measured sequentially for each axis. In the framework of this project a simulation tool was developed to find the optimal operating parameters.

This poster will give an overview of the current design and of the simulations that were used to optimize the measurement sequence. Further, an outlook is given on future on-site measurements and intermediate goals of the project.

Q 56.22 Thu 17:00 KG I Foyer

Laser stabilization for a compact multi-axis inertial navigation system — •Philipp Barbey[1], Matthias Gersemann[1], Mouine Abidi[1], Ashwin Rajagopalan[1], Ann Sabu[1], Polina Shelingovskaia[1], Yueyang Zou[1], Christian Schubert[2], Dennis Schlippert[1], Ernst M. Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt

The application of cold and ultracold atoms in light-pulse atom interferometry enables the development of new technologies, including inertial measurement systems for navigation. Quantum sensors utilizing atom interferometry offer precise measurements of inertial forces with a focus on long-term stability, yet developing sensors for field applications requires advancements in the development of compact and scalable technology.

One of our goals is the development of new electronics that control the sensor's operation. In the past, these have often been built using analog components only. Especially in the feedback loops controlling the laser frequency, digital components offer more flexibility in adjusting operational parameters. This poster presents an overview of our proposed quantum sensor, highlighting new developments for laser stabilization, partially based on the ARTIQ experiment control framework.

We acknowledge financial support by the DFG EXC2123 QuantumFrontiers - 390837967 and by the DLR with funds provided by BMWK under Grant No. DLR 50NA2106 (QGyro+)

Q 56.23 Thu 17:00 KG I Foyer

State-of-the art suppression of seismic noise for Very Long Baseline Atom Interferometry — •Kai C. Grensemann, Jonas Klussmeyer, Klaus Zipfel, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The Hannover Very Long Baseline Atom Interferometer (VLBAI) facility offers exciting capabilities for absolute precision gravimetry with applications in geodesy and tests of fundamental physics. Its 10 m baseline enables free fall times of up to $2T = 2.4\,\mathrm{s}$ and therefore large measurement sensitivity scale factors $k_{\mathrm{eff}}T^2$. However, the sensitivity to vibrational noise of the inertial reference mirror increases similarly. To attenuate seismic vibrations coupling to the mirror, the VLBAI facility is equipped with a state-of-the-art in-vacuum seismic attenuation system (SAS).

Here we present the recently installed SAS with its range of featured sensors and actuators, as well as a first benchmark of the passive vibration attenuation performance. Passive attenuation in all degrees of freedom is achieved by three sets of inverted pendula suspended from geometric antispring filters with a low vertical resonance frequency of 320 mHz. Residual motion at the resonance can be damped actively using three seismometers spread over the suspended platform and six voice coil actuators in a feedback loop. Furthermore, a central out-of-loop low-noise seismometer provides data to post-correct the interferometer measurements. We estimate that the SAS in combination with post-correction will allow instabilities of $\approx 4 \cdot 10^{-10} \frac{\mathrm{m}}{\mathrm{s}^2}$ at 1 s, close to the shot-noise limit of $\approx 2 \cdot 10^{-10} \frac{\mathrm{m}}{\mathrm{s}^2}$ for 10^6 atoms.

Q 56.24 Thu 17:00 KG I Foyer

Theory of multi-axis atom interferometric sensing for inertial navigation — •Christian Struckmann, Knut Stolzenberg, Dennis Schlippert, and Naceur Gaaloul — Leibniz University Hannover, Institute of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany

Quantum sensors based on the interference of matter waves provide an exceptional measurement tool for inertial forces, and are considered next generation accelerometers for applications in geodesy, navigation, or fundamental physics due to the absence of drifts. However, conventional atom interferometers are only able to measure inertial forces along one single axis, resulting in one acceleration and one rotation component. To determine the motion of a moving body, an inertial measurement unit needs to measure the acceleration and rotation of the body along three perpendicular directions. Extending this atom interferometeric measurement scheme to multiple components would normally require the subsequent measurement along a differently oriented axis.

In this contribution, we present our theory and simulation efforts based on experimental schemes enabling three dimensional sensing using simultaneously operated single-axis atom interferometers. We detail the sensitivity and dimensionality scaling of the measurement as well as its potential and improvement avenues.

This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 56.25 Thu 17:00 KG I Foyer

Scenario building for Earth Observation Space Missions Featuring Quantum Sensors — •Gina Kleinsteinberg, Christian Struckmann, Naceur Gaaloul, and for the CARIOQA Consortium — Institute of Quantum Optics, Leibniz University Hanover, Welfengarten 1, 30167 Hanover, Germany

Being extremely sensitive to accelerations and rotations with high stability at low frequencies, atom interferometer configurations offer a versatile approach not only for Fundamental Physics research but also for Earth Observation. The latter is currently gaining more and more significance, as consequences of climate change, e.g. sea level rise and changes in water mass distributions are directly reflected in Earth's gravity field. In order to increase the maturity of quantum sensors in space, the European Commission envisages a quantum pathfinder mission, CARIOQA-PMP (Cold Atom Rubidium Interferometer in Orbit for Quantum Accelerometry - Pathfinder Mission Preparation), to be launched by the end of this decade. In this contribution, we present a simulation tool capable to analyse the mission scenarios for the quantum pathfinder as well as for the follow-on full-fledge quantum gravimetry mission. The mission scenario is developed in close cooperation with the geodesy community within the CARIOQA-PMP project from the classical satellite simulations, the quantum measurement and finally the recovery of the gravity field from the interferometer signal. This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 56.26 Thu 17:00 KG I Foyer

Quantum metrology for levito-dynamics — •Francis Headley — Tübingen Universität

There has been much interest in testing the quantum nature of Gravity through table-top opto-mechanical experiments. In particular levito-dynamic systems have been proposed as ultrasensitive force and acceleration sensors and could thus also become a strong candidate for testing the possibility of entangling two massive objects via the gravitational field. These levito-dynamic set-ups promise low decoherence environments which should allow us to probe the quantum dynamics of massive mechanical objects. We present recent theoretical developments for interferometric experiments which utilise a system of massive particles levitated in superconducting traps. Coupling these mechanical oscillators via Gravity harbours the promise of new types of high fidelity measurement of Newtons constant, as well as providing a new and promising play ground for testing different quantum models.

Q 56.27 Thu 17:00 KG I Foyer

Towards a Miniaturized Spaceborne Rubidium Two-Photon Frequency Reference — •Daniel Emanuel Kohl[1,2], Julien Kluge[1,2], Moritz Eisebitt[1,2], Klaus Döringshoff[1,2], Nicolas Manrique[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik - Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut (FBH), Leibniz-Institut für Höchstfrequenztechnik

We present the development of a miniaturized rubidium two-photon frequency reference using the $5S_{1/2} \rightarrow 5D_{5/2}$ transition at 778.1 nm, developed as a part of the CRONOS project. The project's goal is to demonstrate a micro-satellite-based optical clock in low earth orbit. Optical frequency standards based on frequency modulation spectroscopy of atomic vapor are a promising candidate for realization of compact optical clocks for application in next generation global navigation satellite systems. Rubidium offers a 300 kHz linewidth two-photon transition accessable with inherently Doppler free spectroscopy.

We show a prototype of a compact spectroscopy module achieving fractional frequency instabilities in the regime of $10^{-13}/\sqrt{\tau}$. The design comprises a projected volume below 0.5 l, mass below 1 kg and a power consumption below 10 W. Further we present first results of the utilization of MEMS rubidium vapor cells to reduce the size weight and power budget of the spectroscopy module.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971, 50WM2164.

Q 56.28 Thu 17:00 KG I Foyer

Two-Photon Frequency References for Optical Clocks and Hyperfine Spectroscopy — •Moritz Eisebitt[1,2], Julien Kluge[1,2], Daniel Emanuel Kohl[1,2], Klaus Döringshoff[1,2], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Insitut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik, Humboldt-Universität zu Berlin

We present our monochromatic two-photon frequency references at 778 nm, operating on the $5S_{1/2} \rightarrow 5D_{5/2}$ transition in Rubidium. We use inherently Doppler-free frequency modulation spectroscopy of the approximately 500 kHz broad transition, with detection via the fluorescence at 420 nm. The fractional instability, derived from a beat-note between two independent references, is below $1.7 \cdot 10^{-13}/\sqrt{\tau}$, reaching $6 \cdot 10^{-15}$ for an averaging time τ of 1000 s. We present details on the noise analysis including the influence of residual amplitude modulation and fluctuations in the optical power.

Further, measurements of the dipole, quadrupole and octupole hyperfine structure constants of Rb $5D_{5/2}$ are presented which surpass the precision of the current state-of-the-art values by one order of magnitude.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971, 50WM2164.

Q 56.29 Thu 17:00 KG I Foyer

First aluminium ion clock comparisons at PTB — •Fabian Dawel[1,2], Johannes Kramer[1,2], Marek Hild[1,2], Lennart Pelzer[1], Kai Dietze[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

A single trapped $^{27}Al^+$ ion is an excellent frequency reference for an optical clock, as it is largely insensitive to external field shifts. Achieved inaccuracies are below the 10^{-18} level and thus make aluminum clocks a promising candidate for the re-definition of the SI second and enable for cm-scale height difference measurements in relativistic geodesy. We estimated the systematic uncertainty budget of PTB's Al^+ clock using a single $^{40}Ca^+$ ion as a sensor. Included in the analysis are shifts by black body radiation, collisions with background gas molecules, residual kinetic energy from uncompensated micromotion and the ac Zeeman shift caused by fast oscillating magnetic fields. The statistical uncertainty is measured by comparing Al^+ with the strontium lattice clock at PTB. This clock comparisons also allow us to estimate the absolute frequency and compare it to other frequency ratio measurements.

Q 56.30 Thu 17:00 KG I Foyer

Red-Emitting DBR Laser for Strontium-Based Optical Atomic Clocks — •Sandy Szermer, Nora Goossen-Schmidt, Bassem Arar, Ahmad Bawamia, Jörg Fricke, Jonas Hamperl, Karl Häusler, Andre Maassdorf, Christoph Pyrlik, Max Schiemangk, Hans Wenzel, Andrea Knigge, and Andreas Wicht — Ferdinand-Braun-Institut, Leibnitz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin

Strontium (Sr)-based optical atomic clocks provide promising applications such as improved satellite navigation or fundamental research e.g. redefining the unit of time.

To deliver the repumping wavelengths for a compact, transportable Sr lattice optical clock, we have developed red-emitting distributed Bragg reflector (DBR) ridge waveguide (RW) lasers at 679 nm and 707 nm. A higher-order surface Bragg grating is monolithically incorporated into a section of the RW to achieve frequency selectivity and low frequency noise. We optimised the design of the DBR laser with respect to gain section length and front facet reflectivity. For both wavelengths, the lasers reach FWHM linewidths (β-separation method) of around 1 MHz at optical output powers of more than 70 mW. We present the current status of our work and discuss ongoing life tests for the assessment of the operational reliability.

This work was supported by DLR Space Administration with fund provided by the Federal Ministry for Economic Affairs and Climate Action under grant number 50WM2152 and 50WM2351C.

Q 56.31 Thu 17:00 KG I Foyer

Towards demonstrating a rubidium based optical clock in space — •Nicolas Manrique[1,2], Moritz Eisebitt[1,2], Stephanie Gerken[1], Julien Kluge[1,2], Daniel Emanuel Kohl[1,2], Mathis Müller[1], Norbert Müller[1], Max Schiemangk[1], Dian Zou[1], Klaus Döringshoff[1,2], Andreas Wicht[1], Markus Krutzik[1,2], and the QUEEN/CRONOS Team[1,3,4] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik - Humboldt-Universität zu Berlin — [3]Institut für Luft- und Raumfahrt - Technische Universität Berlin — [4]Menlo Systems GmbH

The QUEEN mission aims to demonstrate an optical atomic clock aboard a micro-satellite in low-earth orbit. The optical clock payload named CRONOS includes a micro-integrated extended cavity diode laser, whose frequency is stabilized to a narrow linewidth Rubidium two-photon transition at 778 nm. A space-borne optical frequency comb transfers the frequency stability of the laser system to the RF regime, providing an electrical clock output at 10 MHz with targeted fractional frequency instabilities better than $3 \times 10^{-13}/\sqrt{\tau}$ over time scales from 1 s to 10^5 s.

Here we present the current design and architecture of the CRONOS payload, targeting a maximum volume of 25 L, mass of 20 kg, and power consumption under 60 W, which shall operate two years in orbit.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50WM2164.

Q 56.32 Thu 17:00 KG I Foyer

A highly stable laser for quantum logic spectroscopy in an optical ^{27}Al$^+$ clock — •Gayatri R. Sasidharan[1,2], Benjamin Kraus[1,2], Fabian Dawel[1,2], Lennart Pelzer[1,2], Constantin Nauk[1,2], Joost Hinrichs[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunchweig, Germany — [2]Leibniz Universität Hannover, Institut für Quantenoptiik, 30167 Hannover, Germany

Optical clocks using trapped ^{27}Al$^+$ clock frequency reaches a fractional frequency uncertainty below 10^{-18} [1]. This makes it a viable candidate in a transportable setup for relative geodesy measurements at cm height resolution. The cooling and detection transitions of Al$^+$ ion is not directly accessible. Therefore, a co-trapped Ca$^+$ ion is used for sympathetic cooling and state readout through quantum logic spectroscopy. Highly stable lasers are needed to address both logic transitions for ^{40}Ca$^+$ and ^{27}Al$^+$. We present a laser system operating at 729 nm and 1068 nm locked to a Fabry-Pérot cavity of length 5 cm with dual wavelength coating maintained at a pressure 3 x 10^{-9} mbar [2]. The 729 nm laser is used for the ^{40}Ca$^+$ logic transition. The 1068 nm laser is frequency quadrupled and used for ^{27}Al$^+$ state preparations and quantum logic operations. The results on stability measurements of two lasers onto the same cavity and correlation measurements in photo-thermal noise are shown.

[1] S. M. Brewer, et al., PRL 123, 033201(2019).
[2] Fabian Dawel, et al., arXiv:2311.11610.

Q 56.33 Thu 17:00 KG I Foyer

Artificial clock transitions with multiple trapped ^{40}Ca$^+$ ions as frequency references — •Kai Dietze[1,2], Lennart Pelzer[1], Ludwig Krinner[1,2], Fabian Dawel[1], Johannes Kramer[1,2], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Bundesallee 100

The statistical uncertainty of trapped ion optical atomic clocks is often limited by the quantum projection noise (QPN) of the underlying quantum system. Low ion numbers, dephasing and transition broadening due to environmental noise or adjacent ions is limiting the transition linewidth and signal-to-noise ratio and therefore the achieavable statistical uncertainty. Here we focus on creating artificial quantum system with the Zeeman states of the $4S_{1/2}$ to $5D_{5/2}$ clock transition of ^{40}Ca$^+$, improving the QPN compared to classical interrogation protocols. We will present our results on creating a frequency reference using continuous dynamical decoupling, mitigating noise from magnetic field fluctuations as well as the quadrupole-shift often limiting larger ion numbers [1]. Furthermore we will present results on using GHZ entangled states between two ions as a frequency reference. These state are designed to be in a decoherence free subspace against magnetic field fluctuations, allowing close to lifetime limited coherence times. We demonstrated QPN-limited relative frequency stability for this system, reaching even below the QPN of uncorrelated atoms for intermediate timescales.

[1] Pelzer *et al.*, arXiv:2311.13736

Q 56.34 Thu 17:00 KG I Foyer

Recent progress on PTB's transportable Al$^+$ ion clock — •Constantin Nauk[1], Benjamin Kraus[1], Joost Hinrichs[1,2], Gayatri Sasidharan[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks demonstrate remarkable fractional systematic and statistical frequency uncertainties on the order of 10^{-18}, opening the door to novel applications. One such application are height measurements in relativistic geodesy at the cm level. However, earth monitoring field campaigns require robust, reliable and transportable hardware.

For this purpose, we are currently setting up a clock based on the ^{1}S$_0 \rightarrow {}^3$P$_0$ transition in ^{27}Al$^+$. A co-trapped ^{40}Ca$^+$ ion allows state detection and cooling through quantum logic spectroscopy and sympathetic cooling.

We present the 19" rack design and the current status of the transportable apparatus. The physics package, including the vacuum system designed for pressure ranges below 10^{-10} mbar, and the surrounding optics are discussed. Notably, we present a combining laser setup that combines laser light for ionization, cooling, state read-out and repumping into one fiber. Additionally, we showcase the performance of the cavity-stabilized clock light fundamental laser with a fractional frequency instability of about $2 \cdot 10^{-16}$ at 1 second.

Q 56.35 Thu 17:00 KG I Foyer

Probing physics beyond the standard model using ultracold mercury — •Thorsten Groh, Sascha Heider, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

Dark matter searches for physics beyond the standard model (SM) range from cosmological observations to high-energy collision experiments and low-energy table-top experiments. The baryon asymmetry of the universe explained by recent baryogenesis therories requires a degree of CP-violation that might result in a measurable atomic electric dipole moment (EDM). High precision spectroscopy of atomic isotope shifts could probe for a new force carrier that directly couples neutrons and electrons [Delaunay, PRD 96, 093001 (2017); Berengut, PRL 120, 091801 (2018)].

Mercury being one of the heaviest laser-coolable elements makes it an ideal platform for beyond SM physics like baryon asymmetry searches [Graner PRL 116, 161601 (2016)]. Excellent for isotope shift spectroscopy it possesses five naturally occurring bosonic isotopes, all of which we laser cool in our lab.

We report on recent improvements and upgrades on the machine for transferring magneto-optically trapped mercury atoms to a high power optical dipole trap. We present latest results on high resolution deep UV laser isotope shift spectroscopy and multidimensional King plot analysis of the nonlinearities. Furthermore we give outlook to beyond the state-of-the-art measurements of the atomic EDM of mercury.

Q 56.36 Thu 17:00 KG I Foyer

Towards an Autonomous Laser System for Operation in Quantum Technology Applications — •Janpeter Hirsch, Martin Gärtner, Stephanie Gerken, Sriram Hariharan, Nora Goossen-Schmidt, Simon Kubitza, Norbert Müller, Max Schiemangk, Christoph Tyborski, Dian Zou, and Andreas Wicht — Ferdinand-Braun-Institut (FBH), Berlin, Germany

In the domain of quantum sensors, compact laser systems with extremely narrow linewidth and precise control over emission frequency and output power are indispensable components. To alleviate the user's workload, expedite operational processes, and reduce the level of expertise required, an automated adjustment of various actuators becomes essential. As part of an integrated solution, we introduce a high-power, narrow-linewidth laser module, complemented by a frequency-tunable reference module, both operating at a wavelength of 767 nm. While the laser module features an active stabilization of the optical resonator length and enables mode-hop-free tuning of the optical emission frequency, the frequency reference module facilitates an accelerated lock-acquisition. Together, these advancements pave the way for more accessible and efficient quantum technology applications.

Acknowledgement: This work was supported by VDI Technologiezentrum GmbH / Federal Ministry of Education and Research (grant numbers: 13N14906, 13N15724), by DLR Space Administration / Federal Ministry for Economic Affairs and Climate Action (grant numbers: 50WM2053, 50WM2152, 50WM2176, 50WM2164) and by Investitionsbank Berlin / European Union (grant number:10168115).

Q 56.37 Thu 17:00 KG I Foyer

Sideband Thermometry on Ion Crystals — •Ivan Vybornyi[1], Laura Dreissen[2,3], Dominik Kiesenhofer[4,5], Helene Hainzer[4,5], Matthias Bock[4,5], Tuomas Ollikainen[4,5], Daniel Vadlejch[2], Christian Roos[4,5], Tanja Mehlstäubler[2,6], and Klemens Hammerer[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany — [3]Department of Physics and Astronomy, LaserLab, Vrije Universiteit, De Boeleaan, 1081 HV Amsterdam, The Netherlands — [4]Universität Innsbruck, Institut für Experimentalphysik, Technikerstraße 25, 6020 Innsbruck, Austria — [5]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, 6020 Innsbruck, Austria — [6]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Coulomb crystals of cold trapped ions are a leading platform for quantum computing, simulations and metrology. For these applications, it is essential to be able to determine the crystal's temperature with high accuracy, which is a challenging task for large crystals due to complex many-body correlations. Recently [arXiv:2306.07880v3] we presented an ion crystal thermometry method that deals with this problem. With two experiments (4 ions 1D linear chain and 19 ions 2D crystal) we test the new method and cross-check it via other techniques. The results confirm the new method being accurate and efficient. Current work aims to generalize ion thermometry for non-thermal states of motion.

Q 56.38 Thu 17:00 KG I Foyer

Nigtrogen vacancy center based magnetometer and gradiometer — •JIxing Zhang, Michael Kuebler, Magnus Benke, Yihua Wang, Anjana Karuvayalil, and Joerg Wrachtrup — 3rd Institute of Physics, University of Stuttgart, 70569 Stuttgart, Germany

Diamond nitrogen vacancy (NV) centers have emerged as a promising platform for quantum sensing with diverse applications spanning multiple disciplines. This research focuses on harnessing the unique capabilities of high-concentration NV centers to achieve unparalleled sensitivity in magnetometry, thereby unlocking significant potential for magnetic measurements. In comparison to established magnetometry technologies like SQUID and OPM, NV-based magnetometry stands out by offering a larger dynamic range, enhanced bandwidth, and superior spatial resolution. This abstract introduces a novel magnetic gradiometer, comprising two NV-based magnetometers strategically designed to resolve weak magnetic signals from a test object amid challenging high environmental magnetic field noise conditions. The study showcases the design principles and presents compelling measurement results for the NV ensemble gradiometer. Our findings highlight its remarkable potential for capturing magnetic signals associated with human muscle and brain activity. This breakthrough not only underscores the versatility of NV-based magnetometry but also positions it as a transformative technology for advancing our understanding of complex biological processes.

Q 56.39 Thu 17:00 KG I Foyer

Optimal Ramsey interferometry with echo protocols based on one-axis twisting — •Maja Scharnagl[1], Timm Kielinski[2], and Klemens Hammerer[2] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany — [2]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany

We study a variational class of generalized Ramsey protocols that include two one-axis twisting (OAT) operations, one performed before the phase imprint and the other after. In this framework, we optimize the axes of the signal imprint, the OAT interactions, and the direction of the final projective measurement. We distinguish between protocols that exhibit symmetric or antisymmetric dependencies of the spin projection signal on the measured phase. Our results show that the quantum Fisher information, which sets the limits on the sensitivity achievable with a given uniaxially twisted input state, can be saturated within our class of variational protocols for almost all initial twisting strengths. By incorporating numerous protocols previously documented in the literature, our approach creates a unified framework for Ramsey echo protocols with OAT states and measurements.

Q 56.40 Thu 17:00 KG I Foyer

Progress towards a continuous wave superradiant Calcium Laser — •David Nak and Andreas Hemmerich — Institut für Quantenphysik, Universität Hamburg, Hamburg, Deutschland

Superradiant Lasers are suitable as light sources with ultralow bandwidth, as their emission frequency is only weakly dependent on an eigenfrequency of the laser cavity. They can be used as a read-out tool for precise optical atomic clocks. Currently, our experiment loads cold Calcium-40 atoms from a magneto optical trap into a one-dimensional optical lattice prepared inside a cavity. By incoherent population of the metastable triplet state, pulsed superradiant emission on the intercombination line was realized [1].

We will present our progress with the advancement of our bichromatic MOT and our incoherent repumping protocol, which will enable us to maintain the superradiant state for an extended period of time.

[1] T. Laske, H. Winter, and A. Hemmerich, Pulse Delay Time Statistics in a Superradiant Laser with Calcium Atoms, Phys. Rev. Lett. 123, 103601 (2019).

Q 56.41 Thu 17:00 KG I Foyer

spin-dependent exotic interactions — •lei cong[1,2], wei ji[1,2], pavel fadeev[1], filip ficek[1], min jiang[1], victor v. flambaum[1], haosen guan[1], derek f. jackson kimball[1], mikhail g. kozlov[1], yevgeny v. stadnik[1], and dmitry budker[1] — [1]Helmholtz-Institut, Mainz 55128, Germany, and others — [2]Equal contribution

The fifth force may arise due to "new physics" beyond the standard model. We focus on the spin-dependent fifth forces that are mediated by new particles, such as spin-0 particles (axion and axion-like-particles) and spin-1 particles (e.g. light Z' particle or massless paraphoton). These new ultralight particles are also candidates for dark matter and dark energy, and may also break fundamental symmetries. Spin-dependent interactions between fermions have been extensively searched for in experiments, employing methods such as comagnetometers, nitrogen-vacancy spin sensors, and precision measurements of atomic and molecular spectra [1, 2, 3]. Our research involves a theoretical reassessment of exotic spin-dependent forces [4]. It produces a systematic and complete set of interaction potentials expressed in terms of reduced coupling constants. We will conduct an extensive analysis of the existing body of experimental literature on spin-dependent fifth forces, which will produce systematic exclusion plots. This will lead to a comprehensive understanding of the current research landscape and provide insights for further research.

References: [1] Wei Ji, et al. *PRL*, **130**, 133202, 2023. [2] Xing Rong, et al. *NC*, **9**, 739, 2018. [3] Filip Ficek, et al. *PRL*, **120**, 183002, 2018. [4] Pavel Fadeev, et al. *PRA*, **99**, 022113, 2019.

Q 56.42 Thu 17:00 KG I Foyer

Low-noise magnetic sensing with tin-vacancy centers — •Gesa Welker[1], Yufan Li[1], Toeno van der Sar[1], and Richard Norte[2] — [1]Faculty of Applied Sciences, TU Delft, The Netherlands —

[2]Faculty of 3mE, TU Delft, The Netherlands

Similar to the well-known nitrogen-vacancies (NV), tin-vacancy (SnV) defects in diamond have optically active spins. One of their most intriguing properties is their resilience to electrical noise, which is four orders of magnitude higher than for NV centers [1]. SnV centers are therefore expected to be formidable magnetic field sensors that outperform NV-based sensors at cryogenic temperatures. To the best of our knowledge, SnV centers have not been used for sensing since their experimental realization in 2017 [2,3]. We develop a fiber-coupled scanning-SnV-magnetometry setup, based on earlier work in our group with fiber-coupled NV centers [4]. We attach a diamond nanobeam with SnV centers to a tapered optical fiber, which we then scan across a sample. Fiber coupling increases sensitivity via a high optical excitation and collection efficiency. It allows using low laser power, thereby bringing millikelvin magnetometry into reach. Furthermore, fiber coupling eliminates the need for realignment of free-space optics when cooling to cryogenic temperatures. Our goal is achieving a sensitivity high enough to study weak magnetic signatures in condensed matter systems, e.g. 2D materials or correlated electron systems. [1] De Santis et al., PRL 127, 147402 (2021) [2] Iwasaki et al., PRL 119, 253601 (2017) [3] Ditalia Tchernij et al., ACS Photonics 4, 2580-2586 (2017) [4] Li et al., ACS Photonics 10, 1859-1865 (2023)

Q 57: Poster VIII

Time: Thursday 17:00–19:00 Location: Aula Foyer

Q 57.1 Thu 17:00 Aula Foyer

Implementation of a laser system for alkali vapor MEMS cell activation — •Janice Wollenberg[1], Jenichi Clairvaux Felizco[2], Julien Kluge[1,2], Daniel Emanuel Kohl[1,2], Kai Gehrke[2], Andreas Thies[2], Klaus Döringshoff[1,2], Olaf Krüger[2], and Markus Krutzik[1,2] — [1]Institut für Physik - Humboldt-Universität zu Berlin — [2]Ferdinand - Braun-Institut, Leibniz - Institut für Höchstfrequenztechnik

We present a laser system designed for activating and characterizing Rubidium vapor MEMS cells. These mm-size cells are intended for use in chip-scale optical frequency references utilizing two-photon spectroscopy of Rubidium at 778 nm.

Our approach involves employing a high-power laser at 1064 nm to release elementary Rb from a dispenser pill within the MEMS cell. Within the dual-chambered MEMS cell, one chamber contains the Rb dispenser pill, which gets activated by the 1064 nm laser and releases Rb vapor into the second spectroscopy chamber via micro-channels. There, we use Doppler-free saturation spectroscopy of the D2 transition at 780 nm to characterize the quality of the cells. The outcomes of this work are expected to contribute to the development of optical frequency references, expanding their potential applications, e.g., in optical atomic clocks based on two-photon spectroscopy of Rubidium.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971.

Q 57.2 Thu 17:00 Aula Foyer

Status of a modern Michelson Morley experiment using ultrastable cryogenic cavities and shot noise limited cryogenic detectors — •Erich Günter Leo Pape, Evgeny Kovalchuk, and Achim Peters — Newtonstr. 15, 12489, Berlin, Humboldt Universität zu Berlin, Institut für Physik

We present advancements in cryogenic experiments, showcasing an optical sapphire cavity setup for a Michelson-Morley experiment on Lorentz violations with a target frequency stability of $10^{-16} Hz/\sqrt{Hz}$. Furthermore, we present our cryogenic detectors using a cryogenic MESFET preamplifier for high bandwidth shot noise-limited performance at $10\mu W$ laser power, contributing to enhanced precision in signal detection.

Q 57.3 Thu 17:00 Aula Foyer

Optofluidic lasing within a fiber-based microresonator — •Mustafa Gerdan, Shalom Palkhivala, Larissa Kohler, and David Hunger — Karlsruhe Institute of Technology, Karlsruhe, DE

Most biochemical processes which are of interest to biological examinations occur in aqueous environments and require sensitive measurement techniques. The process of laser generation is highly sensitive to subtle changes in environmental conditions, making a lasing-based sensor a promising candidate for biosensing. As a first step towards optofluidic lasing-based sensing, we have demonstrated a dye microlaser in a fiber-based Fabry-Perot optical resonator [1] using rhodamine 6G as a gain medium. The resonator is integrated into a microfluidic system, allowing reactions within the gain medium to directly influence the lasing of the microlaser. By monitoring the lasing output, e.g. via the lasing threshold, small changes in the vicinity can be investigated. We shall report work towards constructing an optofluidic microlaser using europium-based molecules [2] as the gain medium. Europium presents distinct advantages in contrast to organic dyes, including its resistance to bleaching, precisely defined energy levels of the 4f-states, narrow linewidth of f-f transitions, and long lifetime. Such a device shows promise as a sensitive method in the monitoring of biochemical processes, such as small concentration changes or cell dynamics in a solution phase.

[1] Kohler, L. et al. Nat Commun 12, 6385 (2021)
[2] Kuzmanoski, A. et al. Zeitschrift für Naturforschung B, Vol. 69 (Issue 2), pp. 248-254 (2014)

Q 57.4 Thu 17:00 Aula Foyer

Status of Laser Cooling at the FAIR SIS100 — •Denise Schwarz[1], Jens Gumm[1], Benedikt Langfeld[1], Sebastian Klammes[2], Danyal Winters[2], and Thomas Walther[1,3] — [1]TU Darmstadt — [2]GSI Darmstadt — [3]HFHF Darmstadt

Bunched relativistic ion beams with a narrow momentum distribution are key for precision experiments at accelerator facilities. To reduce the relative momentum distribution, the principle of laser cooling can be utilized.

Past experiments conducted at the Experimental Storage Ring (ESR) at GSI have demonstrated the advantage of both cw and pulsed UV laser in decreasing the relative momentum distribution of bunched relativistic ion beams.

To achieve even better result, the integration of three laser systems, one cw and two pulsed laser, has been proposed for laser cooling at the FAIR SIS100. To implement this new scenario, overlap in space, time and energy of the three laser beams with the ion beam needs to be optimized.

This work presents the specifics of laser cooling with the integration of three laser systems and focuses mainly on creating good spatial overlap between ion and laser beams, also taking into account the need for active laser beam stabilization.

Q 57.5 Thu 17:00 Aula Foyer

Utilizing coupled mode theory for surrogate modeling with 3D FDTD simulations of GaAs-based surface Bragg grating — •Yasmin Rahimof, Igor Nechepurenko, Sten Wenzel, Reza Mahani, and Andreas Wicht — Ferdinand-Braun-Institut (FBH)

Diode lasers with remarkably narrow linewidths, like Extended Cavity Diode Lasers (ECDLs), are vital components for photonic systems which have various applications in quantum computing, optical atomic clocks and quantum sensors based on atom interferometry. The monolithic ECDL (mECDL) represents an advanced photonic device, integrating electro-optical efficiency and compactness onto a single GaAs chip. This study introduces a surrogate model for the Bragg gratings in mECDL.

Recent mECDL improvements focus on optimizing Bragg gratings to reduce frequency noise. Achieving this goal involves utilizing Finite-Difference Time-Domain (FDTD) simulations to investigate the reflectance spectra. However, conducting these simulations is computationally complex. This complexity presents challenges, particularly in the context of large-scale structure simulations. To overcome this problem, we have employed a more efficient approach by integrating 3D FDTD with 1D coupled mode theory. This "hybrid" method created an accurate surrogate model for predicting Bragg grating's reflectance spectrum, drastically reducing simulation time. In summary, our research introduces a robust surrogate model for mECDL Bragg grating, enabling precise performance predictions instead of implementing time-consuming 3D simulations.

Q 57.6 Thu 17:00 Aula Foyer

Tunability of a Pulsed UV Laser System for Laser Cooling of Relativistic Bunched Ion Beams — •Tamina Grunwitz, Benedikt Langfeld, and Thomas Walther — Technische Universität Darmstadt

The usage of laser cooling as the only cooling method at FAIR's new synchrotron SIS100 promises a narrow momentum distribution of the relativistic bunched ion beams. In order to address a wide range of ion velocities, the pulsed laser system used for cooling must have the ability to be tunable at the cooling wavelength in the UV region.

In this contribution, we present our tunable pulsed laser system at a center wavelength of 257 nm. For tunability of the whole system, the seed wavelength can be tuned over a range of 3 nm around the center wavelength of 1030 nm. To ensure that this change in wavelength is converted to the UV region at maximum performance, both angle adjustments of the fiber amplifiers ASE filters and phase matching of the second SHG stage (critical phase matching) must be automated. In this work, we will present recent progress on these automations and their performance.

Q 57.7 Thu 17:00 Aula Foyer

Generation of cw UV radiation using elliptical focusing enhancement cavities — •Jens Gumm[1], Daniel Preissler[1], and Thomas Walther[1,2] — [1]TU Darmstadt — [2]HFHF Darmstadt

Long term cw laser operation with high output power in the UV spectral range is of great interest in many scientific and commercial applications.
Generation of cw-UV light is often realized by resonant second harmonic generation employing β-Barium Borate (BBO) as the nonlinear optical medium. A known parasitic effect in BBO is the degradation of the crystal due to two-photon absorption.
We theoretically showed that elliptical focusing can lead to higher conversion efficiencies compared to the spherical optimum and decreases the peak intensity in the nonlinear crystal.
Experimentally, we demonstrated UV powers in excess of 2W.

Q 57.8 Thu 17:00 Aula Foyer

Defect Dynamics and Microstructure in Colloidal Glasses Using Holographic Optical Tweezers — •Rhuthwik Sriranga[1,2], Ratimanasee Sahu[1], Diptabrata Paul[1], GV Pavan Kumar[1], Vijayakumar Chikkadi[1], and Patrick Windpassinger[2] — [1]Indian Institute of Science Education and Research Pune, India — [2]Institute of Physics, Johannes Gutenberg-Universität Mainz

This study delves into the intricate relationship between plastic activity and microstructure in amorphous materials using optical tweezer techniques. Shear fields in a colloidal monolayer are generated using holographic optical tweezers with a Laguerre-Gaussian beam and a spatial light modulator. With this setup, we examine the relationships between defect dynamics and microstructure in a quasi-2D system of colloidal glasses, including the orientation of defects with respect to the shear direction. Using time-shared optical tweezers to trap more than 250 particles, we investigate the effect of random pinning on the phonon modes in colloidal crystals and glasses. Through these optical techniques, we aim to bridge the gap in understanding the behaviour of disordered solids and their response to external stimuli, providing valuable insights into the fundamental mechanics of amorphous substances.

Q 57.9 Thu 17:00 Aula Foyer

Advancing Fiber Cavity QED with Precision Mirror Fabrication — •Nick Theilacker, Patrick Maier, Gregor Bayer, Selene Sachero, Robert Berghaus, David Opferkuch, and Alexander Kubanek — University Ulm , Institute for Quantum Optics, Albert-Einstein-Allee 11, 89081 Ulm, Germany

In quantum photonic applications, achieving efficient single-photon exchange requires high-quality resonators. Researchers focus on reducing mode volume (V) and increasing quality factor (Q) in Fabry-Pérot resonators. This involves crafting concave structures with a small radius of curvature (ROC) and low surface roughness (Osc). Here, we report on our latest effort to optimize the ratio of Q over V to estabish concave mirrors for next generation F.-P. microcavities.

Q 57.10 Thu 17:00 Aula Foyer

Noise cancelling in solid-state lasers — •Thomas Konrad[1], Tobias Steinle[1], Roman Bek[2], Michael Scharwaechter[2], Matthias Seibold[2], Andy Steinmann[1], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Twenty-One Semiconductors GmbH, Allmandring 3, 70569 Stuttgart

Ultra-low-noise laser sources are key for fast and precise measurements, for instance in the fields of bioimaging, near-field optical microscopy, and gravitational wave detection. Besides efficient detection, the laser noise figure is the dominating factor that should be exploited to the fundamental limit demarked by the shot noise. Higher laser noise can be compensated by longer averaging, but the penalty in measurement time scales with the square of the excess noise. Especially with biological samples a significant longer measurement time can alter the results. Therefore, noise reduction of the system itself is more beneficial than longer measurement durations.

In this work we investigate an active noise cancelling scheme in solid state lasers, which are commonly used in many high precision applications. Instead of reducing the noise after the laser, we investigate approaches to reduce the laser noise at its source, namely the laser cavity itself. Due to a resonant coupling between the lifetime of the gain medium and the intracavity laser field, relaxation oscillations are one dominating noise phenomenon in solid-state lasers. Our approach is to actively modulate the absolute gain in a solid-state laser against the relaxation oscillations to achieve wide-band ultra-low intensity noise.

Q 57.11 Thu 17:00 Aula Foyer

Machine-aided Autonomous Dispersion Compensation of Femtosecond Pulses in a Fiber-Integrated System — •Mehmet Müftüoglu, Bennet Fischer, and Mario Chemnitz — Leibniz-Institute of Photonic Technologies, Albert-Einstein-Str. 9, 07745 Jena, Germany.

Dispersion compensation is crucial for optical communication and nonlinear optics. Typical compensation methods rely on bulky dispersive elements such as prisms and gratings or dispersive compensating fibers(DCFs). In this work, we compensated 6-meter fiber system dispersion to achieve transform-limited femtosecond pulses at the lead fiber's distal end. Wave shaping manipulates individual frequencies in the frequency domain, enhancing control over the phase profile. Our setup consists of a laser, an amplifier(EDFA), a waveshaper, an autocorrelator, and a computer. Our methodology incorporates a feedback loop between the autocorrelator and the waveshaper to optimize the phase of an ultrashort pulse autonomously. For unsupervised system control, we implement the Particle Swarm Optimization algorithm to compensate for target system configuration (e.g. fiber lengths or pump power). The swarm algorithm optimizes the seven free parameters of a polynomial Taylor expansion in 6th order. In our experiments, we consistently approached transform-limited pulses in various scenarios, achieving durations of 120 fs at lower power and 72 fs at higher power. Our machine-assisted compression method is applicable to supercontinuum spectra excitation in highly nonlinear fibers.

Q 57.12 Thu 17:00 Aula Foyer

Coherent control in V-type systems: Simulation insights using intense two-dimensional coherent spectroscopy — •Rishabh Tripathi, Krishna Kumar Maurya, and Rohan Singh — Indian Institute of Science Education and Research, Bhopal

Our study investigates coherent control in V-type three-level systems using high-intensity, ultrafast laser pulses, explored through two-dimensional coherent spectroscopy (2DCS). Employing numerical solutions of the optical Bloch equations, we analyze the response of a V-type system to Gaussian pulses of 10 fs and 120 fs. The research reveals that shorter pulses induce uniform Rabi oscillations, whereas longer pulses result in complex quantum interference and state-specific population dynamics. This distinction underscores the pivotal role of pulse duration and spectral properties in modulating quantum interactions.

Our 2DCS simulations, utilizing phase-cycling methods, provide insights into the system's spectral response in both perturbative and non-perturbative regimes. These simulations reveal the manipulation of spectral peak amplitudes and phases by adjusting the pulse areas, demonstrating control over the system.

This work contributes to the understanding of light-matter interactions in quantum systems and highlights the potential of tailored laser pulses for advanced coherent control, with implications for atomic vapors, semiconductor nanostructures, and photonics research.

Q 57.13 Thu 17:00 Aula Foyer

Towards frequency comb Raman spectroscopy for quantum logic — •Elyas Mattivi — Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck, Austria

One of the most attractive quantum computing platforms is that of atomic ions. We aim to investigate an alternative approach that substitutes atomic ions with molecular ions, which allows for the utilization of rotational degrees of freedom for quantum information encoding. However, due to the complex internal structure of molecules, advanced methods are required to manipulate and readout their quantum states. In order to prepare, control, and characterize molecules at the quantum level, we are developing a setup for two-beam frequency comb Raman spectroscopy.

The two-beam frequency comb Raman setup allows precise control over driving rotational transitions in molecular ions. We will drive two-beam frequency comb Raman carrier transitions between the electronic D-levels in Ca+. The same system will be used for driving rotational state transitions in CaH+ and CaOH+. The possibility of directly driving sideband transitions with the frequency comb will also be explored. Driving rotational transitions in molecules, especially sideband transitions, requires higher intensities, necessitating the use of an amplifier. Dispersion in the optical path also decreases Raman efficiency. My project focuses on the amplification and dispersion compensation of the comb light used in this Raman setup.

Q 57.14 Thu 17:00 Aula Foyer

Towards state preparation, readout, and control of polyatomic molecular ions using quantum logic spectroscopy — •Mariano Isaza-Monsalve — University of Innsbruck, Innsbruck, Austria

Molecular ions offer more degrees of freedom than atomic ions. These larger Hilbert spaces are rich and interesting landscapes to explore, possibly enabling quantum information applications such as quantum error correcting (QEC) schemes not available in atomic ions. This requires efficient and precise control of the molecular ion states. Co-trapping a molecular ion with an atomic ion facilitates state preparation and readout via quantum logic spectroscopy. Our group aims to use calcium-based molecules, e.g., CaH+ or CaOH+, co-trapped with a 40Ca+ ion for exploring these applications in QEC and precision spectroscopy. Coherent control within a rotational manifold of a molecular ion can be achieved by driving two-beam Raman transitions, as direct transitions between the sublevels in the same manifold are forbidden by selection rules.

Q 57.15 Thu 17:00 Aula Foyer

Enhancing multi-electron event reconstruction for delay line detectors using deep learning — •Tobias Volk[1], Marco Knipfer[1], Stefan Meier[1], Jonas Heimerl[1], Sergei Gleyzer[2], and Peter Hommelhoff[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Department of Physics and Astronomy, University of Alabama, Tuscaloosa, AL 35487, USA

Accurate detection of multiple, closely spaced electrons is of utmost interest for correlation experiments [1, 2]. However, the reconstruction of individual electrons becomes particularly challenging if multiple electrons arrive closely confined in space and time. One possibility for a multi-hit capable detector system are so-called delay line detectors, where the core aspect of electron event reconstruction is the detection of voltage peaks. While classical methods work well on single electron events, they fail to reconstruct multiple close electrons arriving within a narrow time window. The result is a profound dead zone hindering the evaluation of especially interesting, close electron events. To address this challenge, we introduce a deep learning approach for the spatio-temporal reconstruction of multi-electron events [3]. We achieve a dead radius of 2.5 mm, reducing the classical limit by a factor of 8 while improving the overall resolution. Based on this, already existing delay-line setups can be improved posterior, not limited to electrons.

[1] S. Meier et al., Nature Physics 19, 1402-1409 (2023)
[2] R. Haindl et al., Nature Physics 19, 1410-1417 (2023)
[3] M. Knipfer et al., arXiv:2306.09359 (2023)

Q 57.16 Thu 17:00 Aula Foyer

Optical coherence tomography of encapsulated two-dimensional materials using extreme ultraviolet radiation from high-harmonic generation sources — •Felix Wiesner[1], Julius Reinhard[1,2], Johann J Abel[1], Martin Wünsche[1], Gerhard G Paulus[1,2], and Silvio Fuchs[1,2,3] — [1]Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena, Jena, Germany — [2]Helmholtz Institute Jena, Jena, Germany — [3]University of Applied Sciences Mittweida, Laserinstitut (LHM, Mittweida, Germany

Atomically thin materials, such as graphene or transition-metal dichalgonides (TMDs), demonstrate exciting physical properties. For the majority of applications, the monolayers must be encapsulated for passivation, protection, or functionalization. Although many techniques exist to characterize the monolayers themselves, methods for imaging encapsulated monolayers are lacking.

Coherence tomography with extreme ultraviolet light (XCT) is a high resolution, high sensitivity technique for axial imaging. The high spatial resolution is enabled by the use of broadband extreme ultraviolet (EUV) light produced by high-harmonic generation (HHG). Consequently, XCT promises to provide important information on the structure of samples containing encapsulated monolayers.

This study applies XCT to the investigation of graphene layers in a silicon encapsulation. Mono-, bi-, and trilayers of encapsulated graphene can be differentiated. Furthermore the interface roughness and the thickness of native oxide layers can be reconstructed. We discuss the applicability of the method to additional types of samples.

Q 57.17 Thu 17:00 Aula Foyer

Evolution of Floquet topological quantum states in drivensemiconductors — Andreas Lubatsch[1] and •Regine Frank[2,3] — [1]Physikalisches Institut, Rheinische Friedrich Wilhelms Universitaet Bonn — [2]College of Biomedical Sciences, Larkin University, Miami, Florida, USA — [3]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain

Spatially uniform excitations can induce Floquet topological bandstructures within insulators which have equal characteristics to those of topological insulators. We demonstrate the evolution of Floquet topological quantum states for electromagnetically driven semiconductor bulk matter. We show the direct physical impact of the mathematical precision of the Floquet-Keldysh theory when we solve the driven system of a generalized Hubbard model with our framework of dynamical mean field theory (DMFT) in the non-equilibrium with physical consequences for opto-electronic applications. [1] A. Lubatsch, R. Frank, Eur. Phys. J. B (2019) 92: 215 [2] A.Lubatsch, R. Frank, Symmetry 2019, 11, 1246 [3] P.-C. Chang, J.G.Lu, Appl. Phys. Lett. 2008, 92, 212113

Q 58: Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)

Time: Friday 11:00–13:00 Location: HS 1098

Q 58.1 Fri 11:00 HS 1098

Accurate and efficient Bloch-oscillation-enhanced atom interferometry — •Florian Fitzek[1,2], Jan-Niclas Kirsten-Siemss[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

Bloch oscillations of atoms in optical lattices offer a powerful technique to significantly enhance the sensitivity of atom interferometers by orders of magnitude. To fully exploit the potential of this method, an accurate theoretical description of losses and phases beyond current treatments is essential. In this work, we introduce a comprehensive theoretical framework for Bloch-oscillation-enhanced atom interferometry [Fitzek *et al.*, arXiv:2306.09399]. We confirm its accuracy through comparison with an exact numerical solution of the Schrödinger equation [Fitzek *et al.*, Sci Rep 10, 22120 (2020)]. Using our approach, we define the fundamental efficiency and accuracy limits of Bloch-oscillation-enhanced atom interferometers and establish design criteria to achieve their saturation. We compare these limits to current state-of-the-art atom interferometers and formulate requirements for the improvement of future quantum sensors.

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 58.2 Fri 11:15 HS 1098

Quantum fluctuations in one-dimensional supersolids — •Chris Bühler, Tobias Ilg, and Hans Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart

In one dimension, quantum fluctuations prevent the appearance of long-range order in a supersolid, and only quasi-long-range order can survive. We derive this quantum critical behavior and study its influence on the superfluid response and properties of the solid. The analysis is based on an effective low-energy description accounting for the two coupled Goldstone modes. We find that the quantum phase transition from the superfluid to the supersolid is shifted by quantum fluctuations from the position where the local formation of a solid structure takes place. For current experimental parameters with dipolar atomic gases, this shift is extremely small and cannot be resolved yet, i.e., current observations in experiments are expected to be in agreement with predictions from mean-field theory based on the extended Gross-Pitaevskii formalism.

https://journals.aps.org/prresearch/abstract/10.1103/PhysRevResearch.5.033092

Q 58.3 Fri 11:30 HS 1098

Realizing freely programmable passively phase-stable 2D optical lattices — David Wei[1,2], •Daniel Adler[1,2], Kritsana Srakaew[1,2], Suchita Agrawal[1,2], Pascal Weckesser[1,2], Immanuel Bloch[1,2,3], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany

Ultracold atoms in optical lattices have become a vital platform for experimental quantum simulation, enabling the precise study of a variety of quantum many-body problems. For most experiments, the layout of the lattice beams restricts the accessible lattice configurations and thus the underlying physics. Here, we present a novel tunable lattice, which provides programmable unit cell connectivity and in principle allows for changing the geometry mid-sequence. Our approach builds on the phase-stable realization of a square or triangular lattice combined with microscopically projected repulsive local potential patterns. We benchmark the performance of this system through single-particle quantum walks in the square, triangular, kagome, and Lieb lattices. In the strongly correlated regime, we microscopically characterize the geometry dependence of the quantum fluctuations.

Q 58.4 Fri 11:45 HS 1098

Phase diagram of the extended anyon Hubbard model in one dimension — •Imke Schneider[1], Martin Bonkhoff[2], Kevin Jägering[1], Shijie Hu[3], Axel Pelster[1], and Sebastian Eggert[1] — [1]University of Kaiserslautern-Landau, Landesforschungszentrum OPTIMAS — [2]Universität Hamburg — [3]Beijing Computational Science Research Center

Anyons with arbitrary exchange angle can be realized using ultracold atoms in optical lattices. Here, we study the anyonic extended Hubbard model in one dimension. At unit filling a repulsive next-nearest neighbor interaction generally leads to gapped phases but it is far from trivial which correlations are the dominant ones as a function of topological exchange angle and on-site interaction U. We find that a careful derivation of all terms in the Luttinger liquid theory predicts an intermediate phase between a Mott insulator for large repulsive U and a charge density wave at negative U. As a function of exchange angle the intermediate phase changes from Haldane insulator for pseudo bosons to a dimerized phase for pseudo fermions at an interesting multicritical point. Our results are confirmed by extensive numerical simulations.

Q 58.5 Fri 12:00 HS 1098

Spontaneous ignition of an ion trap engine — •Peter Stabel, Diego Fieguth, and James Anglin — RPTU Kaiserslautern

Do the microscopic roots of thermodynamics extend even before the onset of chaotic ergodization, into the integrable Hamiltonian mechanics of small, isolated systems? Here we propose a set of experiments on the three-dimensional motion of a single ion in a linear Paul Trap, in which the focus is not on any form of thermalization, but on the engine-like secular transfer of energy between fast and slow degrees of freedom, analogous to the rapid motions of hot gas particles slowly lifting a weight. The ion's three motional degrees of freedom constitute the entire system, which is isolated and undriven; a high-frequency transverse vibrational mode of the ion plays the role of a battery or fuel tank, or hot reservoir to power steady axial motion against an opposing force. We show that this combustion engine-like system can generically run autonomously, but that only under a certain more stringent condition can the engine also start autonomously. This non-trivial condition for autonomous starting of the engine-like process can be derived from unitarity, via the classical Kruskal-Neishtadt-Henrard theorem and its recent quantum extension. Although these post-adiabatic theorems do not involve ergodization, they do involve a certain increase of phase space areas, or subspace dimensions, and may play a role similar to that played macroscopically by thermodynamics, in constraining the design of microscopic autonomous machines.

Q 58.6 Fri 12:15 HS 1098

Emergence of a Bose polaron in a small ring threaded by the Aharonov-Bohm flux — •Fabian Brauneis[1], Areg Ghazaryan[2], Hans-Werner Hammer[1,3], and Artem Volosniev[2] — [1]Technische Universität Darmstadt, Department of Physics, 64289 Darmstadt, Germany — [2]Institute of Science and Technology Austria (ISTA), 3400 Klosterneuburg, Austria — [3]ExtreMe Matter Institute EMMI and Helmholtz Forschungsakademie Hessen für FAIR (HFHF), 64291 Darmstadt, Germany

The model of a ring threaded by the Aharonov-Bohm flux underlies our understanding of a coupling between gauge potentials and matter. The typical formulation of the model is based upon a single particle picture, and should be extended when interactions with other particles become relevant. Here, we illustrate such an extension for a particle in an Aharonov-Bohm ring subject to interactions with a weakly interacting Bose gas. Our findings demonstrate that the system's ground state can be effectively characterized using the Bose polaron concept – a particle dressed by interactions with a bosonic environment. Our results suggest the Aharonov-Bohm ring as a platform for the few-to many-body crossover of quasi-particles that arise from an impurity immersed in a medium.

This work has received funding from the DFG Project no. 413495248 [VO 2437/1-1].

Q 58.7 Fri 12:30 HS 1098

Effective Theory for the Gaudin-Yang model — •Timothy George Backert[1], Hans-Werner Hammer[1,3], Artem Volosniev[2], Fabian Brauneis[1], Joachim Brand[4], and Matija Čufar[4] — [1]Technische Universität Darmstadt, Department of Physics — [2]Institute of Science and Technology Austria (ISTA) — [3]ExtreMe Matter Institute EMMIand Helmholtz Forschungsakademie Hessen für FAIR (HFHF) — [4]New Zealand Institute for Advanced Study, Massey University, New Zealand

We investigate the crossover from a Bardeen-Cooper-Schrieffer superfluid with loosely bound Cooper pairs to a Bose-Einstein condensate of tightly bound dimers (molecules) for a one-dimensional spin-1/2 Fermi gas (Gaudin-Yang model [GY]) on a ring. We obtain exact Bethe-Ansatz solutions which describe the BCS-BEC crossover in the form of a transition from a (BCS-like) gas of loosely bound fermion pairs to a Tonks-Girardeau gas of tightly bound dimers. For the experimentally relevant case of an external potential only numerical solutions can be obtained. In order to obtain analytical insights into the case with an external potential, we set up an effective theory with fermions and dimers as degrees of freedom and determine the coupling constants by matching to the Bethe-Ansatz results. We find good agreement with the numerical results for small particle numbers. This paves the way for the exploration of many-body systems using this effective theory. Supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) * Project-ID 279384907 * SFB 1245.

Q 58.8 Fri 12:45 HS 1098

Three-charged-particle systems in the framework of coupled coordinate-space few-body equations — •Renat Sultanov — Odessa College, Department of Mathematics, 201 W. University Blvd. Odessa, TX USA

We study *three-charged-particle* low-energy elastic collision and particle-exchange reaction with special attention to the systems with Coulomb and an additional nuclear interaction employing a close-coupling expansion scheme to a set of coupled two-component few-body equations [1]. First we apply our formulation to compute low-energy elastic scattering phase shifts for the $d+(t\mu^-)_{1s}$ collision, which is of significant interest for the muon-catalyzed-fusion D-T cycle. Next, we study the particle-exchange reaction $d+(pX^-)\to p+(dX^-)$ with the long-lived elementary heavy lepton stau X^- which can play a critical role in the understanding of the Big-Bang nucleosynthesis and the nature of dark matter. We also study the total cross sections and rates for two particle-exchange reactions involving antiprotons ($\bar{p}$), deuteron (d) and triton (t), e.g., $\bar{p}+(d\mu^-)_{1s}\to(\bar{p}d)_{1s}+\mu^-$ and $\bar{p}+(t\mu^-)_{1s}\to(\bar{p}t)_{1s}+\mu^-$, where μ^- is a muon. The effect of the final state short-range strong ($\bar{p}d$) and ($\bar{p}t$) nuclear interactions is significant in these reactions, which increases the reaction rates by a factor of ≈3. Additionally (if time permits), a 3-body $\bar{p}+Mu$ collision will be discussed, where Mu is a muonium atom [2].

1. R. A. Sultanov and S. K. Adhikari, Phys. Rev. C 107, 064003 (2023).

2. R. A. Sultanov and D. Guster, J. Phys. B 46, 215204 (2013).

Q 59: Lasers II

Time: Friday 11:00–13:00 Location: HS 1015

Q 59.1 Fri 11:00 HS 1015

Low Repetition Rate Optical Frequency Combs for Precision Spectroscopy — •Muhammad Thariq[1], Francesco Canella[1,2,3], Johannes Weitenberg[1,4], Fabian Schmid[1,5], Paras Dwivedi[1,6], Gianluca Galzerano[3], Theodor W. Hänsch[1,6], Thomas Udem[1,6], and Akira Ozawa[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Dipartimento di Fisica, Politecnico di Milano, 20133 Milan, Italy — [3]Istituto di Fotonica e Nanotecnologie - Consiglio Nazionale delle Ricerche, 20133 Milan, Italy — [4]Fraunhofer-Institut für Lasertechnik ILT, 52074 Aachen, Germany — [5]Institute for Quantum Electronics, ETH Zürich, 8093 Zurich, Switzerland — [6]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 Munich, Germany

High harmonic generation (HHG) can be used to generate extreme ultraviolet (XUV) frequency combs (FCs) for precision spectroscopy. Unfortunately, HHG requires very high peak power for frequency conversion. In this work, we propose to use a low repetition rate FC to drive HHG, where the repetition rate is reduced using an AOM-based pulse picker, while the peak power of the FC is increased, allowing HHG to be performed at moderate average powers. A 40 kHz repetition rate FC is demonstrated from a 40 MHz repetition rate mode-locked Yb:KYW oscillator. Pulse amplification to 4.175 μJ pulse energy is achieved using multi-stage Yb:LuAG amplifiers, with future plans to reach up to 50 μJ. The results show the prospect of generating XUV frequency combs with average powers below 10 W, making XUV FCs more accessible to researchers across disciplines.

Q 59.2 Fri 11:15 HS 1015

Methods for focusing VUV laser light onto a single ^{229}Th ion — •Tamila Rozibakieva[1], Irtiza M. Hussain[1], Lilli Löbell[1], Daniel Moritz[1], Kevin Scharl[1], Johannes Weitenberg[2], Markus Wiesinger[1], Stephan H. Wissenberg[2], and Peter G. Thirolf[1] — [1]Ludwig-Maximilians-Universität München (LMU) — [2]Fraunhofer Institute for Laser Technology (ILT), Aachen

Direct frequency-comb spectroscopy is a promising way for narrow-band nuclear laser excitation. The combination of a VUV frequency comb being developed at Fraunhofer ILT and a cryogenic Paul trap set up at LMU Munich as part of the ERC synergy project "Thorium Nuclear Clock", will enable us to excite the isomeric first excited state in ^{229}Th using laser radiation of 148.7 nm wavelength, an important step towards the realization of a nuclear clock that can be used to search for new physics beyond the standard model. For the single-ion nuclear clock, a laser-cooled $^{229}Th^{3+}$ ion must be irradiated with a single mode of a frequency comb with narrow bandwidth. When focusing to a spot with a diameter of 3 μm, we envisage sufficient laser radiation intensity for driving nuclear Rabi oscillations. For such tight focusing of a VUV beam on a single ion, it is important to choose the proper optical elements that minimize optical aberrations and power losses due to interaction with optical materials. Different methods and simulations for focusing a VUV beam down to 3 μm, such as a spherical mirror, an off-axis parabolic mirror and an achromatic lens, will be presented. Funding: ERC Synergy project, Grant Agreement No. 856415 and BaCaTec (grant 7-2029-2).

Q 59.3 Fri 11:30 HS 1015

Spectroscopic isotope separation in hot rubidium vapor — •Timon Damböck[1], Denis Uhland[1], Gunnar Langfahl-Klabes[1], Robert Löw[2], and Ilja Gerhardt[1] — [1]Leibniz Universität Hannover, Appelstrasse 2, 30167 Hannover — [2]Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

Whether for medical applications, radiation protection or the utilization in physical metrology – having access to a pure or enriched amount of a single isotope can be a major advance. Natural abundant rubidium is composed of ^{85}Rb and ^{87}Rb. Since these isotopes differ in their nuclear spin, the hyperfine groundstates are spectrally well separated. Our experimental setup consists of two vapor cells which are interconnected by a capillary. Resonant high power lasers are used to exert a light induced drift on the individual rubidium isotopes [1]. Changes in isotope concentration in the cells are measured using absorption spectroscopy. This talk will discuss our progress to enrich and separate rubidium isotopes in hot atomic vapor using light induced drift.

[1] Okamoto, M. et al. Observation of Light-Induced Drift Effect of Rubidium by Using Two Diode Lasers for Pumping and Re-Pumping. Materials Transactions. 49, 11 (2008), pp. 2632-2635.

Q 59.4 Fri 11:45 HS 1015

Bioelectronics with ultrashort pulses — •Hrvoje Skenderović[1], Mario Rakić[1], and Vedran Djerek[2] — [1]Institute of Physics, Bijenicka cesta 46, 10000 Zagreb, Croatia — [2]Physical Department University of Zagreb, Bijenička cesta 32 cesta

Two dimensional golden electrodes are drawn on a flexible polyimide sheet by ultrashort laser pulses. Laser parameters for efficient ablation of the metal (about 10 nm thin) without damaging the PI substrate (about 50 micrometers thin) were investigated. The fabrication is optimised by spatial beam shaping.

Q 59.5 Fri 12:00 HS 1015

Nonliner Dynamics in Optical fibers for Sensing — •Glitta Rosalia Cheeran, Bennet Fischer, and Mario Chemnitz — Leibniz Institute of Photonic Technology

The study of nonlinear dynamics in optical fibers has attracted significant attention due to their applications in multi-frequency laser engineering and nonlinear imaging. In particular, supercontinuum generation, a complex nonlinear process that leads to the generation of new frequencies over hundreds of terahertz, has emerged as a versatile ultra-broadband source of light. This complex process depends on various factors, including the properties of the input pulse and the optical fiber involved. Our objective is to exploit the phase and amplitude sensitivity of supercontinuum generation for sensing by examining alterations of the spectral features of the output spectrum when an ultrashort pulse travels through a highly nonlinear fiber. The aim is to comprehend this nonlinear behavior through numerical methods and utilize these dynamics to create highly sensitive devices that can measure both the amplitude and phase of a sample object with high accuracy. In the presentation, we will introduce the uncommon concept of utilizing supercontinuum generation as a sensor instead of a source. We demonstrate a model sensing system, featuring an artificial spectral resonance as a narrowband frequency window, called "bit", within the spectral bandwidth of a 100 fs input pulse defined around 1550 nm. The sensitivity of supercontinuum spectra is then measured using different statistical methods. The next step is to utilize the simulation to examine realistic gas or liquid resonances.

Q 59.6 Fri 12:15 HS 1015

Ophthalmic Surgeries with Picosecond Laser Pulses — •Michael Körber[1,2], Jakob Fellinger[3], Milan Fritsche[1], Andreas Giese[1], Konstantina Kostourou[4], Daniel Kopf[3], Manfred Kottcke[1], Francesco Luciani[5], Josef M. Schmidbauer[2,5], Jonathan Wenk[1], and Bernd Braun[1] — [1]Nuremberg Institute of Technology, Nuremberg, Germany — [2]Paracelsus Medical University, Nuremberg, Germany — [3]MONTFORT Laser GmbH, Götzis, Austria — [4]NANEO Precision IBS Coatings GmbH, Lindau, Germany — [5]Klinik Nürnberg Nord, Nuremberg, Germany

We demonstrate the advancement of various ophthalmic surgeries by using picosecond laser pulses. The surgeries evaluated were iridotomy, capsulotomy, selective laser-trabeculoplasty and lens fragmentation. The tests were executed on porcine eyes. We used a standard two-stage 12 ps laser and a novel ultra-compact 130 ps laser, as well as state-of-the art Nd:YAG nanosecond lasers as reference to current surgery methods. The picosecond results were significantly better in all aspects tested compared to nanoseconds: The pulse energy could be lowered to some tens of microjoule instead of some millijoule, and the tissue ablation is more precise, more deterministic and less frayed. Furthermore, we measured large differences in shock wave pressures between the pulse lengths. Similar differences were found for the heat input. The results could be transferred to human tissue samples and showed the same advantages. In summary, we achieved substantial benefits with picosecond laser pulses. Thus, the ultra-compact picosecond laser provides a stable basis for a new generation of ophthalmic lasers.

Q 59.7 Fri 12:30 HS 1015

Far-field petahertz sampling of plasmonic fields — •Kai-Fu Wong[1,2], Weiwei Li[3,4], Zilong Wang[3,4], Vincent Wanie[2], Erik Månsson[2], Dominik Höing[1,5], Johannes Blöchl[3,4], Thomas Nubbemeyer[3,4], Andrea Trabattoni[2,6], Holger Lange[1,5], Francesca Calegari[1,2], and Matthias F. Kling[3,4,7] — [1]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Center for Free-Electron Laser Science, DESY, Notkestr. 85, 22607 Hamburg, Germany — [3]Max Planck Institute of Quantum Optics, MPQ, Hans-Kopfermann-Straße 1, 85748 Munich, Germany — [4]Ludwig-Maximilians-Universität München, LMU, Am Coloumbwall 1, 85748 Munich, Germany — [5]Institute of Physical Chemistry, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany — [6]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [7]SLAC National Accelerator Laboratory, Stanford University, 2575 Sand Hill Rd, Menlo Park, 94025 California, USA

We demonstrate the realtime observation of linear plasmonic fields by optical field sampling. A comparison between non-resonantly and resonantly excited samples shows that dephasing features of the resonantly excited case sustain into the far-field domain. Our findings also demonstrate the ability to manipulate the spectral properties of ultrashort laser pulses by plasmonic samples, which can act as metasurfaces.

Q 59.8 Fri 12:45 HS 1015

X-ray photon diagnostics at the European X-ray Free Electron Laser — •Jan Grünert, Joakim Laksman, Jia Liu, Wolfgang Freund, Tuba Conka Yildiz, Florian Dietrich, Naresh Kujala, Theophilos Maltezopoulos, and Andreas Koch — European XFEL, Holzkoppel 4, 22869 Schenefeld

The European X-ray Free-Electron Laser (European XFEL), the world's largest and brightest X-ray free-electron laser, went into operation in 2017. It is a large-scale accelerator-based photon source that provides beams of ultrashort (femtosecond), highly coherent and very intense (exceeding 10^{13} photons per pulse) X-ray pulses at high repetition rate (up to 4.5 MHz) to scientific users in various fundamental science fields like bio-molecular dynamical structure determination, femtosecond chemistry, materials research under extreme conditions and many more.

This contribution provides an overview of the x-ray photon diagnostics for this facility, the diagnostics commissioning and their application for commissioning of the facility as well as exciting results from the first years of user operation. The beam properties assessed by photon diagnostics include per-pulse intensity, beam position and shape, lateral dimensions, spectral properties and temporal characteristics.

This contribution strives to provide an overview for newcomers to the field of ultrafast X-ray science, but at the same time include new developments and recent results, which will be mentioned for the experts.

Q 60: Quantum Computing and Simulation I

Time: Friday 11:00–13:00 Location: Aula

Q 60.1 Fri 11:00 Aula

A quantum perceptron gate and a classical Toffoli gate with microwave-driven trapped ions — •Patrick H. Huber[1], Patrick Barthel[1], Sougato Bose[3], Juan José García-Ripoll[4], Johann Haber[1], Yasser Omar[2], Sagar Pratapsi[2], Erik Torrontegui[4], and Christof Wunderlich[1] — [1]University of Siegen, Germany — [2]Universidade de Lisboa, Portugal — [3]University College London, UK — [4]Instituto de Física Fundamental IFF-CSIC, Madrid, Spain

Direct implementation of multi-qubit gates with three or more qubits circumvents decomposition into two-qubit operations, effectively reducing the required depth of quantum circuits. Using the inherent all-to-all coupling in a trapped ion quantum computer, we experimentally realize classical Toffoli and perceptron gates with three microwave-driven hyperfine qubits using $^{171}Yb^+$ ions. The classical Toffoli gate is used to efficiently implement a half-adder. The perceptron gate, when nested with other perceptrons, can be used as universal approximator. Both, the perceptron and Toffoli gates are implemented by a continuous microwave driving field, while the qubits' coherence is protected by pulsed dynamical decoupling. We report the implementation of a two-layer neural network using successive perceptron gates. Here the $^{171}Yb^+$ ions are stored in a linear Paul trap exposed to a permanent magnetic field gradient.

Q 60.2 Fri 11:15 Aula

Fast, high-fidelity gates on trapped-ion qubits at Oxford Ionics — •Clemens Löschnauer[1], Amy Hughes[1], Raghavendra Srinivas[1], Jacopo Mosca Toba[1], Marius Weber[1], Maciej Malinowski[1], Roland Matt[1], Steven King[1], Clemens Matthiesen[1], Thomas Harty[1], and Chris Ballance[1,2] — [1]Oxford Ionics, Oxford, UK — [2]Department of Physics, University of Oxford, Oxford, UK

Electronic control of trapped-ion qubits using oscillating magnetic field gradients has delivered some of the highest-fidelity quantum gates ever reported [1, 2]. However, two-qubit entangling operations using this method are typically slower than laser-based gates, limiting overall computing speeds. We demonstrate high-fidelity two-qubit entangling gates with a duration of 100 μs using a chip trap with integrated microwave antenna, thereby reaching the typical speed of laser-based gates in a highly scalable architecture.

[1] T. P. Harty *et al.*, *Phys. Rev. Lett.* **117**, 140501 (2016)
[2] R. Srinivas *et al.*, *Nature* **597**, pp 209-213 (2021)

Q 60.3 Fri 11:30 Aula

Register-based trapped-ion quantum processor on a linear paul trap — •Rodrigo Munoz[1], Florian Ungerechts[1], Janina Bätge[1], Axel Hoffmann[1,2], Teresa Meiners[1], Brigitte Kaune[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

A promising approach for a trapped-ion based quantum computer is the quantum-charge-coupled-device architecture, as it enables scalability by use of micro-fabrication methods. While using a junction naturally allows all-to-all connectivity of the qubit-array, it is more time efficient to resort to swapping operations for a certain fraction of qubit-shuffles. We present a trap design based on a linear Paul trap that is capable of driving near-field gradient two-qubit gates as well as swapping, merging and splitting two-ion crystals. It also features storage registers using the bucket brigade approach. We will show simulation results that allow extraction of ions from the storage registers as well as merging and swapping.

Q 60.4 Fri 11:45 Aula

Chip based integrated photonics - one key element for upscaling the performance of ion-based quantum computer — •Steffen Sauer[1,2,3], Anastasiia Sorokina[1,2], Carl Grimpe[3], Guochun Du[3], Elena Jordan[3], Fatemeh Salahshoori[3], Tanja Mehlstäubler[3,4,5], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [3]Physikalisch- Technische Bundesanstalt, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nano- und Quantenengineering, Hannover, Germany

The use of compact, robust, and highly scalable quantum experiments will become an increasingly important factor in the coming decades. Chip-integrated photonics offers the perfect solution for a wide range of applications in quantum technology. By miniaturizing and integrating photonic components into a chip, advantages such as improved control and manipulation of light (beam waists of a few μm) to atoms are made possible. Combined with surface traps for ions, photonic layers in the trap realize the scalability of ion-based quantum computers. Within the joint project ATIQ, we develop integrated photonics for an ion-based quantum computer with the goal to realize 40 qubits (ions). We present simulations and measurements of our integrated optical components, such as waveguides or outcouplers, chip designs, and characterization setups for linear and circular light across the UV to IR wavelength range.

Q 60.5 Fri 12:00 Aula

Trapped-ion electric field gates — •Rima X. Schüssler, Matteo Mazzanti, Clara Robalo Pereira, Nella Diepeveen, Louis Gallagher, Zeger Ackerman, Arghavan Safavi-Naini, and Rene Gerritsma — University of Amsterdam, Amsterdam, The Netherlands

Trapped ions are an optimal platform for quantum computation. We plan to combine ions with optical microtraps and oscillating electric fields for a new type of two-qubit geometric phase gate, shown theoretically in [1]. This gate has the advantage that it does not require ground state cooling of the ions. Additionally, the ions involved in the gate can be freely chosen by aligning the tweezers on them. As the electric field couples to all ions equally, the gate works even in very long ion chains.

In our experiment, we use an equidistant ion chain of $^{171}Yb^{+}$ ions in a segmented 3D Paul trap. The tweezer shape are produced by a spatial light modulator, while single ion addressing is done by an acousto optical deflector.

The current experimental status as well as steps taken to align the tweezers on the ions will be presented.

[1] Mazzanti, M., Schüssler, R.X., Espinoza, J.A., Wu, Z., Gerritsma, R. and Safavi-Naini, A., 2021. Trapped Ion Quantum Computing Using Optical Tweezers and Electric Fields. Physical Review Letters, 127(26), 260502

Q 60.6 Fri 12:15 Aula

Fast, robust and laser-free universal entangling gates for trapped-ion quantum computing — •Markus Nünnerich[1], Patrick Barthel[1], Patrick Huber[1], Dorna Niroomand[1], Christof Wunderlich[1], Daniel Cohen[2], and Alex Retzker[2] — [1]Department of Physics, School of Science and Technology, University of Siegen, 57068 Siegen, Germany — [2]Racah Institute of Physics, Hebrew University of Jerusalem, 91904 Jerusalem, Israel

Entangling gates are an essential building block of any quantum processor, ideally working at high speeds in a in a robust and scalable manner. We introduce and experimentally realize a novel Mølmer-Sørensen-type entangling gate. We implement double-dressing of qubit states [1], thus protecting their coherence and simultaneously inducing the gate interaction. Only a single modulated RF driving field per ion is used. The gate is implemented with trapped 171Yb+-ions in a static magnetic gradient of 19 T/m. We generate symmetric and antisymmetric Bell states in 300 us with fidelities better than 97 %. This is an order-of-magnitude improvement in gate time compared to previous entangling gates using the same small magnetic gradient. [2, 3]. In higher magnetic field gradients, already available, this entangling gate speed can be further improved.

[1] D. Farfurnik et al, Phys. Rev. A, 96, 013850 (2017) [2] Ch. Piltz et al, Sci. Adv.2, e1600093 (2016) [3] P. Barthel et al, New J. Phys., 25, 063023 (2023)

Q 60.7 Fri 12:30 Aula

Towards an entangling gate between bosonic qubits in trapped ions — •Stephan Welte, Moritz Fontboté-Schmidt, Martin Wagener, Edgar Brucke, Paul Röggla, Ivan Rojkov, Florentin Reiter, and Jonathan Home — ETH Zurich, Zurich, Switzerland

Encoding quantum information in a harmonic oscillator provides a resource-efficient platform for quantum error correction. A promising code is Gottesman-Kitaev-Preskill (GKP) encoding [1], which was realized both in trapped ions [2, 3] and superconducting qubits [4]. State preparation, single qubits rotations, readout, and error correction have been realized in both architectures. However, a universal two-qubit gate has yet to be demonstrated. I will describe our work towards an entangling gate between GKP qubits prepared in the motional modes of Calcium ions in a Paul trap. The modes are coupled via the Coulomb repulsion approximating a beam splitter interaction. Together with squeezing operations, this interaction can realize the desired universal gate. In theoretical work, we investigate this gate for experimentally realistic parameters and finite energy states [5]. In parallel, we are developing an apparatus for an experimental implementation, including the fabrication of a novel ion trap and the implementation of individual addressing with tightly focused laser beams.

[1] D. Gottesman, A. Kitaev, and J. Preskill. PRA 64, 012310 (2001) [2] C. Flühmann et al. Nature 566, 513(2019) [3] B. de Neeve et al. Nat. Phys. 18, 296 (2022) [4] V. Sivak et al. Nature 616, 50 (2023) [5] I. Rojkov et al. arXiv:2305.05262 (2023)

Q 60.8 Fri 12:45 Aula

Multi-Band Matching Network for a Microwave Surface-Electrode in a High Fidelity Trapped-Ion Quantum Processors — •Axel Hoffmann[1], Florian Ungerechts[2], Rodrigo Munoz[2], Janina Bätge[2], Teresa Meiners[2], Brigitte Kaune[2], Dirk Manteuffel[1], and Christian Ospelkaus[2,3] — [1]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstr. 9A, 30167 Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100,38116 Braunschweig, Germany

Trapped-ion quantum processors with integrated microwave conductors for near-field quantum control are a promising approach for scalable quantum computers. To reduce error sources and allow high fidelity it is not only the microwave electrode integrated in the processor chip that has to be designed carefully. The connection to the source must as well be efficiently designed to enable error reduction. Different approaches to match integrated and external sources to the quantum processors microwave electrode are presented. Here, the reduction of error sources due to inherent electromagnetic behavior and sensitivity to fabrication tolerances are the main focus. The main problem sources and methods to overcome them are discussed. These include electromagnetic simulations and measurement routines.

Q 61: Trapped Ions (joint session Q/A)

Time: Friday 11:00–13:00 Location: HS 1199

Invited Talk Q 61.1 Fri 11:00 HS 1199

Photonic integration for trapped-ion quantum metrology — •Elena Jordan[1], Guochun Du[1], Carl-Frederik Grimpe[1], Fatemeh Salahshoori[1], Markus Kromrey[1], Atasi Chatterjee[1], Anastasiia Sorokina[2,3], Steffen Sauer[1,2,3], Anton Peshkov[1,2], Gillenhaal Beck[4], Karan Mehta[5], Stefanie Kroker[1,2,3], Andrey Surzhykov[1,2,3], and Tanja Mehlstäubler[1,6,7] — [1]PTB, Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany — [3]Laboratory for Emerging Nanometrology Braunschweig, Germany — [4]Institut für Quantenelektronik ETH Zürich, Switzerland — [5]School of Electrical and Computer Engineering Cornell University, Ithaca, NY 14850, USA — [6]Institut für Quantenoptik Leibniz Universität Hannover, Germany — [7]Laboratorium für Nano- und Quantenengineering Leibniz Universität Hannover, Germany

Integrated photonics make ion trap setups scalable to large numbers of ions, help to compactify the setup and improve the robustness against vibrations for portable optical clocks and quantum sensors. We are developing ion traps with integrated photonics for quantum metrology. With photonic design structured light can be generated that, combined with improved pointing stability, enables the excitation of forbidden transitions in trapped ions. For the cooling and addressing of Yb^+ ions wavelengths from UV to NIR are required. The light is coupled in from optical fibers, distributed via waveguides, and coupled out through the surface of the chip via gratings. Our aim is to employ the traps in portable optical clocks that can be used for geodetic measurements.

Q 61.2 Fri 11:30 HS 1199

Apparatus design for scalable cryogenic trapped-ion quantum computing experiments — •Tobias Pootz[1], Lukas Kilzer[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

Future applications for trapped ion quantum computers require a signicant increase in the number of ion qubits and excellent interconnectivity. In my talk I will describe the design of cryogenic demonstrator machines for this task, implementing surface-electrode ion traps mounted on a universal interchangeable socket. The apparatus design is based on a vibration-isolated cold head to cool a cryogenic vacuum system to temperatures below 10 K. The system features several hundred DC control lines to support transport of qubits through dedicated trap structures including junctions, storage, detection and manipulation registers. Multi-qubit quantum gates will be implemented through the use of chip-integrated microwave lines. The system has been designed to accommodate the integration of new components for scaling as the development of the underlying enabling technologies progresses, such as chip integrated waveguides. Multiple setups were built. One setup is based on 9Be+ qubits and 40Ca+ ions for sympathetic cooling; a second setup will be based on 43Ca+ qubits and 88Sr+ cooling ions.

Q 61.3 Fri 11:45 HS 1199

Fabrication of multisegmented ion traps in a specialized cleanroom — •Alexander Müller[1], Jan Müller[1], Björn Lekitsch[1], and Ferdinand Schmidt-Kaler[1,2] — [1]QUANTUM, Institut für Physik, 55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, 55099 Mainz, Germany

Trapped ions are among the leading platforms in quantum computing. We aim to scale up to 50 ions by taking advantage of versatile linear multi-segmented ion traps which combine qubit register reconfigurations [1] and individual addressing of ions in these registers. A fully three-dimensional shaping of electrodes, a homogeneous well-conducting high quality metallic coverage, the precise alignment of trap structures, an excellent optical access, and a fully reliable and repeatable fabrication process are required.

For this we established a special purpose cleanroom. By Selective Laser-induced Etching (SLE) a 3D structure is formed out of fused silica [2]. Metallic sputter deposition results in functional trap chips, which are assembled using a die-bonder, finally fixed on a carrier PCB, and wirebonded for electrical connection of the electrodes. All fabrication steps can be performed in-house and without leaving the cleanroom in a rapid prototyping fashion (<10 days). We report the testing of devices and the trapping of Ca+ ions.

[1] V. Kaushal et al., AVS Quantum Sci.; 2 (1):014101.
[2] S. Ragg et al., Rev. Sci. Instrum.; 90 (10):103203.

Q 61.4 Fri 12:00 HS 1199

Microfabrication of surface ion traps for operation with Strontium Rydberg ions — •Simon Schey[1,2], Michael Pfeifer[1,3], Marion Mallweger[2], Natalia Kuk[2], Ivo Straka[2], Clemens Rössler[1], Yves Colombe[1], and Markus Hennrich[2] — [1]Infineon Technologies Austria AG, Villach, Austria — [2]Stockholm University, Stockholm, Sweden — [3]University of Innsbruck, Innsbruck, Austria

Recently, using Rydberg-states for gate operation in trapped ions has been shown to greatly reduce two qubit gate times down to 700ns [1]. Those experiments were performed in a macroscopic Paul trap at room temperature. We propose to perform similar experiments but in a cryogenic environment as well as on a of surface ion trap chip that is industrially microfabricated at Infineon Technologies [2,3]. This will prove further scalability of this gate scheme.

As UV-Lasers are needed for the Rydberg gate operation, we discuss material and design choices for making our ion trap resilient against radiation down to a wavelength of around 240nm and show successful microfabrication of an ion trap on a sapphire substrate.

[1] Chi Zhang et al., Nature 580, 345-349 (2020)
[2] Ph. Holz et al., Adv. Quantum Technol. 3, 2000031 (2020)
[3] S. Auchter et al., Quantum Sci. Technol. 7, 035015 (2022)

Q 61.5 Fri 12:15 HS 1199

Industrial microfabrication of 2D and 3D ion traps for quantum information processing — •Yves Colombe[1], Silke Auchter[1], Klemens Schüppert[1], Matthias Dietl[1,2], Alexander Zesar[1,3], Jakob Wahl[1,2], Max Glantschnig[1,4], Christian Flasch[1,4], Simon Schey[1,5], Fabian Laurent[1,6], Michael Pfeifer[1,2], Fabian Anmasser[1,2], Michael Hartmann[7], Leon Dixius[7], Mohammad Abu Zahra[7], Jens Repp[7], Nina Megier[1], Matthias Brandl[7], and Clemens Rössler[1] — [1]Infineon Technologies, Villach, Austria — [2]University of Innsbruck, Innsbruck, Austria — [3]University of Graz, Graz, Austria — [4]PTB, Braunschweig, Germany — [5]University of Stockholm, Stockholm, Sweden — [6]Montan University of Leoben, Leoben, Austria — [7]Infineon Technologies, Oberhaching, Germany

Scaling TIQC to thousands of ions requires microfabricated traps produced in highly reliable facilities. Industrial fabrication provides precise process control as well as in-line measurements tools that ensure high reliability and reproducibility.

Various ion trap designs have been produced at Infineon Technologies cleanroom facilities, including 2D ion trap arrays and 3D traps assembled at wafer level. In this talk I will report on our current work towards large-scale ion traps, including fabrication on dielectric substrates (fused silica, sapphire), through-glass-vias, use of Kelvin probe force microscopy for DC surface potential measurements, integration of fs-laser-written optical waveguides, and development of electronic devices that can operate at 4 K.

Q 61.6 Fri 12:30 HS 1199

Optical integration in ion-trap chips at Infineon — •Alexander Zesar[1,2], Jakob Wahl[2,3], Bernhard Lamprecht[5], Philipp Hurdax[5], Klemens Schüppert[2], Clemens Rössler[2], Yves Colombe[2], Silke Auchter[2], Sofia Cano Castro[2,6], Max Glantschnig[2,7], Marco Schmauser[3], Marco Valentini[3], Philipp Schindler[3], Thomas Monz[3,4], and Joachim Krenn[1] — [1]University of Graz, Graz, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]University of Innsbruck, Innsbruck, Austria — [4]Alpine Quantum Technologies GmbH, Innsbruck, Austria — [5]Joanneum Research Materials, Weiz, Austria — [6]Polytecnico di Milano, Milan, Italy — [7]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Trapped ions are among the most researched and advanced quantum computing (QC) hardware platforms. Currently used free-space optics for ion addressing will block upscaling due to beam pointing errors and spatial restrictions. Therefore, future QC architectures with trapped ions require integrated waveguiding and focusing for scalable and stable placement of laser beams in microfabricated ion-trap chips.

This talk gives a concise overview of photonics and optics integration schemes developed at Infineon. We will discuss some of the challenges that come with femtosecond-laser-written waveguides as well as slab waveguides in conjunction with focusing grating couplers, including fiber-to-chip coupling and integration density. The talk concludes with an outlook on scalable ion-trap chips with integrated photonics as a necessary condition for useful trapped-ion quantum computing.

Q 61.7 Fri 12:45 HS 1199

How to Wire a 1000-Qubit Trapped-Ion Quantum Computer — Maciej Malinowski[1], David Allcock[1,2], •Clemens Matthiesen[1], and Chris Ballance[1,3] — [1]Oxford Ionics, Oxford, UK — [2]University of Oregon, Eugene, USA — [3]University of Oxford, Oxford, UK

Scaling up quantum computers requires efficient signal delivery to the quantum processor (the "wiring" challenge). It is likely that integration of control electronics into the processor package will be necessary, but this process is heavily constrained by chip microfabrication and chip operation specifications. Here, we present our WISE (Wiring using Integrated Switching Electronics) architecture as an answer to the wiring question, where judicious integration of simple switching electronics into the ion trap chip is combined with parallel trap electrode control [1]. This significantly reduces the number of signal sources needed, such that a fully connected 1000-qubit trapped ion quantum computer might be operated using only ~ 200 signal sources.

[1] M. Malinowski *et al.*, PRX Quantum **4**, 040313 (2023)

Q 62: Precision Measurements II (joint session Q/A)

Time: Friday 11:00–13:00 Location: HS 1221

Q 62.1 Fri 11:00 HS 1221

Noise Description in Bragg Atom Interferometer Using Squeezed States — •Julian Günther[1,2], Jan-Niclas Kirsten-Siemss[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Hannover, Germany — [2]Institut für Quantenoptik, Hannover, Germany

Using entanglement for N-particle states in matter wave interferometers allows one to outperform the standard quantum limit of $\frac{1}{\sqrt{N}}$ for the uncertainty in the phase measurement. We consider the use of one-axis twisted, spin squeezed atomic states in a Bragg Mach-Zehnder interferometer. We evaluate the phase uncertainty in the phase measurement taking into account the fundamental multi-port and multi-path nature of the Bragg processes, and determine optimally squeezed states for a given geometry.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding organisation DFG (project number 499225223).

Q 62.2 Fri 11:15 HS 1221

Squeezing-enhanced Bragg guided BEC interferometry — •Matthew Glaysher[1], Robin Corgier[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, France

Atom interferometers test fundamental theories and have practical applications such as gravimeters, gradiometers and gyroscopes. Using uncorrelated or classically correlated atomic probes, state-of-the-art devices already operate at the standard quantum limit (SQL) set by their finite baseline and/or atom number resources.

To push the boundaries of compact devices, we study the realisation of a Bose-Einstein condensate (BEC) guided interferometer based on Bragg diffraction [R. Corgier et al., PRA, 103 (2021)]. Taking advantage of the BEC oscillations in the waveguide and the possibility to tune atom-atom interactions we investigate the generation of spin-squeezing dynamics between the two modes in well-defined and well-controlled momentum states. The entangled input state feeds a second interferometer sequence with quantum-enhanced sensitivity capabilities. Realistic aspects of the state-preparation parameters, including diffraction efficiencies and BEC collisions and deformations, are addressed in our scheme.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding organisation DFG (project number 499225223).

Q 62.3 Fri 11:30 HS 1221

Analytical theory of double Bragg diffraction in light-pulse atom interferometers — •Rui Li[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Leibniz University Hanover, Institute for quantum optics, Hannover, Germany — [2]Leibniz University Hanover, Institute for theoretical physics, Hannover, Germany

In this talk, we provide some new physical insights into a recently used tool in atom interferometry, namely the double Bragg diffraction (DBD). We derive an effective two-level-system (TLS) Hamiltonian via Magnus expansion for describing the so-called *quasi-Bragg regime* where most light-pulse atom interferometers are operating. With this effective TLS Hamiltonian, we systematically study the effects of polarization error and AC-Stark shift due to second-order process on the efficiency of double-Bragg beam-splitters. Furthermore, we show that effects of Doppler broadening can be easily included by extending our TLS description to a three-level-system description. With the help of our effective theory, we design an optimal beam-splitter via a time-dependent detuning and show its robustness against polarization error and asymmetric beam-splitting due to Doppler effect.

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 DLR funds from the BMWi (50WM2250A-QUANTUS+)

Q 62.4 Fri 11:45 HS 1221

Wave-packet evolution during laser pulses for single- and two-photon atomic diffraction — •Nadja Augst and Albert Roura — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm

Light-pulse atom interferometry is a valuable tool for high-precision inertial sensing and also offers promising prospects for dark-matter and gravitational-wave detection [1]. This work investigates the wave-packet evolution for an atom's center of mass during a laser pulse of arbitrary duration driving either a single-photon transition or Raman diffraction, and the results are also valid for Bragg diffraction in the deep Bragg regime. In particular, we consider the effects of finite pulse duration on the central trajectory of the atomic wave packets for beam-splitter and mirror pulses as well as pulses with arbitrary pulse areas. Our analysis encompasses a wide range of the cases including square and Gaussian pulse shapes as well as an arbitrary detuning of the central momentum.

While the resulting deviations of the central trajectories are typically quite small, they can have a significant impact on the interferometric phase shift in high-precision measurements and a detailed analysis is therefore important. Our approach relies on a description of the matter-wave propagation in terms of central trajectories and centered wave packets [2].

[1] K. Bongs et al., Nature Rev. Phys. 1, 731 (2019).
[2] A. Roura, Phys. Rev. X 10, 021014 (2020).

Q 62.5 Fri 12:00 HS 1221

Squeezing Enhanced Matterwave Interferometry with BECs — •Christophe Cassens, Bernd Meyer-Hoppe, and Carsten Klempt — Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, D-30167 Hannover, Germany

The gravitational acceleration can be measured with atom interferometers with unprecedented resolution. The ultimate resolution is fundamentally restricted by the standard quantum limit. This restriction can be lifted by operating the interferometer with entangled atoms, which carry quantum correlations among them. Here we present how a squeezed state in the magnetic field insensitive clock states of a Rb-87 BEC of 6000 atoms can be used to improve the sensitivity of an atom gravimeter sequence to -1.5dB below the SQL and -3.3dB below the sensitivity achieved in the same sequence with a coherent state. The here presented technique promises to be applicable in state-of-the-art BEC-based matterwave-interferometers and to increase their sensitivity especially in size, weight and power limited environments.

Q 62.6 Fri 12:15 HS 1221

Simulating matter-wave lensing of BECs in 2D and 3D — •Nico Schwersenz and Albert Roura — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm

The extended microgravity conditions granted by cold-atom experiments in space enable free-evolution times of many seconds, which can be exploited in high-precision measurements based on atom interferometry. However, in order to reach such long evolution times, it is necessary to employ ultracold atoms combined with matter-wave lensing techniques, and a detailed modeling is required.

We present full 3D numerical simulations performed on a GPU cluster of BECs freely expanding for tens of seconds and compare them to effectively 1D and 2D simulations for spherically- and axially-symmetric configurations. A particularly interesting case arises when the lensing potential is applied after the BEC has expanded sufficiently so that the diffraction effects associated with the finite size of the BEC dominate over the mean-field interaction. This enables the validation of our simulations in a regime where the time-dependent Thomas-Fermi approximation fails to provide an accurate description of the dynamics. Finally, as an application of our methods for axially-symmetric configurations, additional features that arise in the anisotropic case will be discussed as well.

Q 62.7 Fri 12:30 HS 1221

Simulation of atomic diffraction through a nanograting — •Matthieu Bruneau[1,2], Charles Garcion[1,2], Julien Lecoffre[2], Quentin Bouton[2], Eric Charron[3], Gabriel Dutier[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Laboratoire de physique des lasers, Université Sorbonne Paris Nord, Villetaneuse, France — [3]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France

Recent advances in the field of cold atoms have made atomic interferometry a versatile and precise tool with various applications, particularly in fundamental physics experiments.

This contribution focuses on the modeling of an experiment involving the diffraction of cold metastable Argon atoms through a transmission nanograting at the Laboratoire de Physique des Lasers. The observed diffraction pattern in this experiment is intrinsically related to the dispersion forces between the atoms and the material. A numerical model of the experiment has been developed, and the influence of these forces has been thoroughly investigated.

The simulation is based on an efficient numerical solution of the time-dependant Schrödinger equation that overcomes the limitations of the more standard semi-classical approach. This methodology provides an accurate description of the diffraction pattern, allowing a Casmir-Polder force measurement beyond the state of the art.

This work is supported by DLR funds from the BMWi (50WM2250A-QUANTUS+).

Q 62.8 Fri 12:45 HS 1221

Double Bragg atom interferometry with Bose-Einstein condensates in microgravity — •Julia Pahl[1], Anurag Bhadane[2], Dorthe Leopoldt[3], Sven Herrmann[4], André Wenzlawski[2], Sven Abend[3], Patrick Windpassinger[2], Ernst M. Rasel[3], Markus Krutzik[1,5], and The QUANTUS Team[1,2,3,4,6,7] — [1]HU Berlin — [2]JGU Mainz — [3]LU Hannover — [4]U Bremen — [5]FBH Berlin — [6]U Ulm — [7]TU Darmstadt

QUANTUS-2 is the 2nd generation mobile atom interferometer operating at the ZARM drop tower in Bremen. With its high-flux, atom chip-based atomic rubidium source, it serves as a pathfinder for future space missions. We are examining key technologies like the generation of Bose-Einstein condensates (BECs), implementation of magnetic lensing or application of various atom interferometry geometries with interferometry times over one second. In this talk, we present our latest results on double Bragg atom interferometry of magnetically lensed rubidium ensembles, using asymmetric Mach-Zehnder interferometers. By exploiting the emerging interferometer fringes we can visualize the anharmonicities of the magnetic lens and determine the interferometer contrast as well as the effective kinetic energy of the ensemble in a single shot. Interferometer times of $2T \approx 1.7\,s$ have been reached.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 1952-1957.

Q 63: Strong Light-Matter Interaction

Time: Friday 11:00–12:45 Location: HS 3118

Q 63.1 Fri 11:00 HS 3118

A stochastic approach to exact dynamics and tunneling in the generalized open Dicke model — •Kai Müller and Walter T. Strunz — Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany

As a fundamental model of quantum optics, the Dicke model has been known and studied for a long time. Recently, however, interest in this model has been revived by the emergence of numerous Cavity QED experiments that allow the controlled realisation of the Dicke model (and its generalised versions) over a wide parameter regime. In the thermodynamic limit $N \to \infty$ the mean-field solution of the Dicke model becomes exact, but to study the emergence of genuine quantum effects in the dynamics of these systems at finite N, a description that goes beyond mean-field theory is required. Here, we present a novel open-system method that allows us to push the boundary for the exact numerical solution of the model up to a mesoscopic number of atoms ($N \approx 500$) and to investigate the deficiencies of a mean-field description in this regime. We explore in which parameter regions true quantum effects, such as tunneling, become relevant for the dynamics and observable in experiments.

Q 63.2 Fri 11:15 HS 3118

Dissipative Dicke time crystals: an atoms' point of view — •Simon B. Jäger, Jan Mathis Giesen, Imke Schneider, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau

We develop and study an atom-only description of the Dicke model with time-periodic couplings between atoms and a dissipative cavity mode. The cavity mode is eliminated giving rise to effective atom-atom interactions and dissipation. We use this effective description to analyze the dynamics of the atoms that undergo a transition to a dynamical superradiant phase with macroscopic coherences in the atomic medium and the light field. Using Floquet theory in combination with the atom-only description we provide a precise determination of the phase boundaries and of the dynamical response of the atoms. From this we can predict the existence of dissipative time crystals that show a subharmonic response with respect to the driving frequency. We show that the atom-only theory can describe the relaxation into such a dissipative time crystal and that the damping rate can be understood in terms of a cooling mechanism.

Q 63.3 Fri 11:30 HS 3118

Quantum Monte Carlo simulation of the Dicke-Ising model on hypercubic lattices — •Anja Langheld, Max Hörmann, and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We study the Ising model in a light-induced quantized transverse field [1, 2] using quantum Monte Carlo to investigate the influence of light-matter interactions on correlated quantum matter. To avoid a direct sampling of the photons, we develop a quantum Monte Carlo algorithm based on the recently introduced wormhole algorithm for spin-boson systems [3], in which the bosonic degrees of freedom are integrated out analytically.

We provide quantitative phase diagrams and critical properties for ferromagnetic as well as antiferromagnetic interactions on hypercubic lattices. For antiferromagnetic interactions, we confirm the existence of a non-trivial intermediate phase, displaying magnetic order and finite photon density at the same time, predicted by a semi-classical mean-field study [1]. However, this intermediate phase turns out to be much smaller and certain phase transitions turn out to be of first order rather than of second order. In the case of ferromagnetic interactions, a change in the order of the quantum phase transition for finite Ising coupling and longitudinal field is observered.

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

Q 63.4 Fri 11:45 HS 3118

Entangled time-crystal phase in an open quantum light-matter system — •Robert Mattes[1], Igor Lesanovsky[1,2], and Federico Carollo[1] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Time-crystals are nonequilibrium many-body phases in which the state of the system dynamically approaches a limit cycle. While these phases are recently in the focus of intensive research, it is still far from clear whether they can host quantum correlations. In fact, mostly classical correlations have been observed so far and time-crystals appear to be effectively classical high-entropy phases. Here, we consider the nonequilibrium behavior of an open quantum light-matter system, realizable in current experiments, which maps onto a paradigmatic time-crystal model after an adiabatic elimination of the light field. The system displays a bistable regime, with coexistent time-crystal and stationary phases, terminating at a tricritical point from which a second-order phase transition line departs. While light and matter are uncorrelated in the stationary phase, the time-crystal phase features bipartite correlations, both of quantum and classical nature. Our work unveils that time-crystal phases in collective open quantum systems can sustain quantum correlations, including entanglement, and are thus more than effectively classical many-body phases.

Q 63.5 Fri 12:00 HS 3118

(Almost) Everything is a Dicke model — •Andreas Schellenberger and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Erlangen, Deutschland

We investigate classes of interacting quantum spin systems in a single-mode cavity with a Dicke coupling, as a paradigmatic example of correlated light-matter systems. Coming from the limit of weak light-matter couplings and large system sizes, we map the relevant low-energy sector of these models onto the exactly solvable Dicke model.

We apply the outcomes to the Dicke-Ising model as a paradigmatic example [1,2], in agreement with results obtained by mean-field theory [2]. We further accompany and verify our findings with finite-size calculations, using exact diagonalization and the series expansion method pcst++ [3].

[1] J. Rohn et al., Phys. Rev. Research, 2, 2020
[2] Y. Zhang et al., Sci. Rep., 4, 2014
[3] L. Lenke et al., Phys. Rev. A, 108, 2023

Q 63.6 Fri 12:15 HS 3118

Optomechanical subradiant states in a many-body cavity QED system — Alexander Baumgärtner[1], •Simon Hertlein[1], Tom Schmit[2], Davide Dreon[1], Carlos Maximo[1], and Giovanna Morigi[2] — [1]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, 8093 Zurich, Switzerland — [2]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

The essence of subradiance lies in its counterintuitive suppression of spontaneous emission, challenging conventional expectations of the collective behavior of scatterers. In the experimental setting of a Bose-Einstein condensate (BEC) system positioned at the mode crossing of two optical cavities, the onset of superradiance in one cavity causes the emergence of a subradiant state in the adjacent cavity. The identification of this subradiant state is facilitated by the revelation of hysteretic behavior during transitions between the superradiant states of the cavities. We investigate experimentally and theoretically the extents of this effect and measure its limitations. This phenomenon, governed by an interplay of constructive and destructive interference, showcases the potential of subradiance as a controllable and exploitable quantum phenomenon in many-body systems interacting with multi-mode cavities.

Q 63.7 Fri 12:30 HS 3118

Breakdown of the Jaynes-Cummings model for cavities with small emitter-induced scattering loss. — •Jürgen Volz, Martin Blaha, and Arno Rauschenbeutel — Institut für Physik, Humboldt-Universität zu Berlin

Strong coupling between a single optical mode and a single quantum emitter is key for a plethora of applications in quantum science and technology and is commonly described by means of the Jaynes-Cummings (JC) model. A key aspect of many cavity quantum electrodynamics (CQED) experiments is to maximize the ratio between the emitter-mode coupling rate and the photon loss rates of the system in order to realize a coherent emitter-light interaction.

Here, we show that, surprisingly, the JC model in general does not provide a valid physical description when the emitter-induced scattering loss becomes too *small*. Indeed, the JC description is only valid when the solid angle covered by the cavity mode is small. We present a Hamiltonian description of CQED that correctly takes into account scattering loss [1]. For the case of large scattering loss, our model's predictions agree with the JC model, while we observe qualitative and quantitative differences in the situation of large solid state angle cavities. As minimizing scattering loss into free-space modes is one of the key design goals for many experimental setups, e.g., in quantum technology, providing an accurate theoretical description is crucial for developing new and optimizing existing cavity-based quantum protocols.

[1] M. Blaha, A. Rauschenbeutel, J. Volz, arXiv:2301.07674 (2023)

Q 64: Solid State Quantum Optics II

Time: Friday 11:00–13:00 Location: HS 3219

Q 64.1 Fri 11:00 HS 3219

Chip-fibre interface for integrated quantum networks — •Tim Engling[1,3], Jonas Zatsch[1,3], Jeldrik Huster[1,3], Simon Abdani[1,3], Christian Schweikert[2], and Stefanie Barz[1,3] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany — [2]Institute of Electrical and Optical Communications Engineering, University of Stuttgart, 70569 Stuttgart, Germany — [3]Center for Integrated Quantum Science and Technology (IQST)

Integrated photonics provides a compact and robust way to process quantum information, and thus, offers a platform for scaling up quantum technologies. We introduce a silicon-on-insulator chip, which offers control of quantum states on the chip, and also, allows converting different degrees of freedom. The manipulation of path is achieved through the use of integrated beam splitters and phase shifters. Furthermore, switching between encoding in path and polarisation, and vice versa, is facilitated by 2D grating couplers. We demonstrate the chip's functionality by utilizing it for the generation, analysis, and conversion of quantum states of light. Our approach enables the connection of multiple integrated photonic chips, laying the foundation for implementing networked protocols in quantum communication and quantum computing.

Q 64.2 Fri 11:15 HS 3219

Towards Cavity-Enhanced Spectroscopy of Single Europium Ions in Yttria Nanocrystals — •Timon Eichhorn[1], Jannis Hessenauer[1], Philippe Goldner[2], Diana Serrano[2], and David Hunger[1] — [1]Karlsruher Institut fuer Technologie, Karlsruhe, Germany — [2]Université PSL, Chimie ParisTech, 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. We study Eu^{3+} ions doped into Y_2O_3 nanoparticles (NPs)[1] 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 [2,3]. A beneficial ratio of the narrow homogeneous line to the inhomogeneous broadening of the ion ensemble makes it possible to spectrally address single ions. The coherent control of the $^5D_0 - ^7F_0$ transition then permits optically driven single qubit operations on the Europium nuclear spin states. A Rydberg-blockade mechanism between nearby ions permits the implementation of a two-qubit CNOT gate to entangle spin qubits and perform quantum logic operations. We observed fluorescence signals from small ensembles of Europium ions at cryogenic temperatures and measured cavity-enhanced optical lifetimes of half the free-space lifetime resulting in effective Purcell-factors of one. We will report on measurements of the optical coherence of small Eu^{3+} ion ensembles and our progress towards single ion readout and control. [1] Nano Lett. 17 (2017) 778-787, [2] New J. Phys. 12 (2010) 065038, [3] New J. Phys. 20 (2018) 095006

Q 64.3 Fri 11:30 HS 3219

Maximizing photon-number resolution from an SNSPD — •Niklas Lamberty, Timon Schapeler, Thomas Hummel, Fabian Schlue, Michael Stefszky, Benjamin Brecht, Christine Silberhorn, and Tim J. Bartley — Institute for Photonic Quantum Systems, Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

Recent work has shown intrinsic Photon-Number Resolution (PNR) of Superconducting Nanowire Single-Photon Detectors (SNSPDs) based on the evaluation of various properties of the electrical output signal. In order to gain a more comprehensive understanding of the features responsible for PNR in SNSPDs, we record a data set of electrical output signals under coherent state illumination and analyze the data using Principal Component Analysis (PCA).

PCA generates a set of basis functions, where the coefficients obtained from projection of the data set onto these basis functions have maximized variance. The basis functions thus indicate areas which are most relevant for PNR and the coefficients indicate which photon-number was measured on the detector.

Using this technique we demonstrate PNR up to four photons and show which features contribute most to the PNR. These results are then verified using a time to digital converter. This intrinsic PNR without the need for multiplexing schemes will simplify many quantum optical experiments like single photon heralding or gaussian boson sampling.

Q 64.4 Fri 11:45 HS 3219

Efficient heralding of pure single-photons at telecom wavelength from pulsed cavity-enhanced SPDC — •Xavier Barcons Planas[1,2], Helen M. Chrzanowski[2], Leon Messner[2], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Institute of Optical Sensor Systems, German Aerospace Center, Berlin, Germany — [3]Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Germany

Entangled quantum states of multiple photons are crucial for pushing the boundaries of photonic quantum technologies. The generation of large multi-photon entangled states demands light sources that provide highly pure photons with high efficiency (either deterministic or heralded), as these factors limit scalability. A popular approach is to herald single-photons from photon-pair sources based on spontaneous parametric down-conversion (SPDC). Despite the spatial and spectral multimode emission of the process, potentially constraining the heralding efficiency and purity, the emitted photons can be engineered with single-mode characteristics, through waveguide geometries [1], group velocity matching techniques [2] or cavity resonators [3]. Here, we present a narrowband (170 MHz) single-photon source at the C-band based on pulsed SPDC in a monolithic crystal cavity. Pure ($P > 95\%$) and fiber-compatible single-photons have been generated with 85% heralding efficiency.

[1] A. Christ *et al.*, Phys. Rev. A **80**, 033829 (2009).
[2] P. J. Mosley *et al.*, Phys. Rev. Lett. **100**, 133601 (2008).
[3] R. Mottola *et al.*, Opt. Express **28**, 3159 (2020).

Q 64.5 Fri 12:00 HS 3219

Quantum optical properties of higher harmonics generated in semiconductors — •Philip Heinzel[1] and René Sondenheimer[1,2] — [1]Friedrich-Schiller-University — [2]Fraunhofer Institute for Applied Optics and Precision Engineering

The exploration of resource state generation for quantum applications has gained increased attention in recent years. Higher harmonics, generated through non-classical effects, stand out as promising candidates for their potential quantum attributes. To delve deeper into this phenomenon, our study focuses on the generation of non-classical light via laser-driven semiconductor intraband excitations, as investigated in [1]. Building upon the parametrical approximation method [2], we adopt the approach outlined in [1] to characterize the generated states. Our objective is to extend the linearized Hamiltonian approximation up to the quadratic order, introducing potential squeezing effects and rotations. Furthermore, we aim to investigate the resulting states, exploring their photon number statistics and quantum effects such as entanglement between different harmonic modes. This examination will provide a more nuanced understanding of the quantum properties inherent in states generated through laser-driven semiconductor intraband excitations.

References
[1]https://arxiv.org/abs/2211.06177v2
[2]https://arxiv.org/abs/2106.15720

Q 64.6 Fri 12:15 HS 3219

Room-temperature ladder-type memory compatible with single photons from InGaAs quantum dots — •Benjamin Maass[1,2,3], Norman Vincenz Ewald[1,2,3], Avijit Barua[3], Stephan Reitzenstein[3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für optische Sensorsysteme, Berlin — [2]Technische Universität Berlin, Institut für Optik und atomare Physik, Berlin — [3]Technische Universität Berlin, Institut für Festkörperphysik, Berlin

The on-demand storage and retrieval of quantum information in coherent light-matter interfaces is a key requirement for future quantum network and quantum communication applications. Non-cryogenic alkali vapor memories offer scalable and robust high-bandwidth storage at high repetition rates which makes them a natural fit for interfaces with single-photon sources. We present a detailed experimental characterization of a room-temperature ladder-type atomic vapor-based memory that operates on the Cs D1 line. We demonstrate on-demand storage and retrieval of weak coherent laser pulses (0.06 photons per pulse) at a high signal-to-noise ratio (SNR=625). The memory reaches a maximum internal storage efficiency of $\eta_{\mathrm{int}} = 16$ % and a 1/e storage time of $\tau_{\mathrm{s}} = 24$ ns. Benchmark properties for the storage of single photons from inhomogeneously broadened state-of-the-art solid state emitters are estimated from the memory's performance. Together with the immediate availability of InGaAs quantum dots emitting at 894 nm this provides a clear prospect for experiments on a heterogeneous on-demand quantum light interface.

Q 64.7 Fri 12:30 HS 3219

Solid state quantum emitter in wide band gap materials — •A. Kumar[1], C. Samaner[2], C. Cholsuk[1], T. Matthes[1], S. Suwanna[3], S. Ateş[2], and T. Vogl[4] — [1]FSU Jena, Germany — [2]İİT, Turkey — [3]Mahidol University, Thailand — [4]TU Munich, Germany

With the rapid development of quantum technology, there has been a growing demand for materials capable of hosting quantum emitters. One such material platform is fluorescent defects in wide band gap materials capable of hosting deep sub-levels within the band gap. Here, we investigate experimentally and theoretically using DFT simulations and compare the fabrication and photophysical properties of quantum emitters in multi-layer mica, hBN and other 3D crystals, such as silicon carbide and gallium nitride which are known to host quantum emitters. We used localized electron beam irradiation process to induce single emitters emitting at 575 nm in hBN with a high yield and emitter ensembles in Mica. The emitters in hBN present a strong correlation with hBN crystal axis, which provides an important step towards the identification of emitters and their formation process. Additionally, we explore temporal polarization dynamics, uncovering a mechanism that governs the time-dependent polarization visibility and dipole orientation of color centers in hBN and diamond. Our further investigation involves the integration of hBN emitters with a nanophotonics platform to develop on-chip quantum light sources for future quantum technology applications.

Q 64.8 Fri 12:45 HS 3219

Characterizing random laser and cavity exiton-polariton supported random laser action in disordered ensembles of the hybrid perovskite CH3 NH 3 PbBr 3 (MAPB) — •Regine Frank[1,2], Paul Bouteyre[3], Hai Son Nguyen[4,5], Christian Seassal[4,5], Emmanuelle Deleporte[3], and Bart A. van Tiggelen[6] — [1]College of Biomedical Sciences, Larkin University, Miami, Florida, USA — [2]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain — [3]Universite Paris-Saclay, ENS Paris-Saclay, CNRS, CentraleSupélec, LuMIn, Gif-sur-Yvette, France — [4]Universite de Lyon, Institut des Nanotechnologies de Lyon, INL/CNRS, Ecole Centrale de Lyon, Ecully, France — [5]Institut Universitaire de France (IUF), Paris, Franceb — [6]Universite Grenoble Alpes, Centre National de la Recherche Scientifique, LPMMC, Grenoble, France

We present semi analytical as well as numerical results (WENO) for photonic transport and Anderson localization of photons in laser active disordered ensembles of the hybrid perovskite CH3 NH3PbBr3 (MAPB) capped by PMMA. We compare experiments of two dimensional and three dimensional transport to time and space resolved numerics coherent to descriminate between directed random laser emission and exciton-polariton supported random laser emission. We present a systematic study of for disordered and quasi ordered ensembles.

Q 65: Ultra-cold Atoms, Ions and BEC V (joint session A/Q)

Time: Friday 14:30–16:30 Location: HS 1010

Q 65.1 Fri 14:30 HS 1010

Pairing dome from an emergent Feshbach resonance in a strongly repulsive bilayer model — •Hannah Lange[1,2,3], Lukas Homeier[1,3], Eugene Demler[4], Ulrich Schollwöck[1,3], Annabelle Bohrdt[3,5], and Fabian Grusdt[1,3] — [1]LMU Munich, Germany — [2]MPI for Quantum Optics, Garching, Germany — [3]Munich Center for Quantum Science and Technology, Germany — [4]ETH Zurich, Switzerland — [5]University of Regensburg, Germany

A key to understanding unconventional superconductivity lies in unraveling the pairing mechanism of mobile charge carriers in doped antiferromagnets, giving rise to an effective attraction between charges even in the presence of strong repulsive Coulomb interactions. In this talk, I will consider a mixed-dimensional t-J ladder, a system that has recently been realized with ultracold atoms [1], and show how it can be extended with a nearest neighbor Coulomb repulsion. With repulsion turned off, the system features tightly bound hole pairs and large binding energies (closed channel). When the repulsion strength is increased, a crossover to more spatially extended, correlated pairs of individual holes (open channel) can be observed. In the latter regime, we still find robust binding energies that are strongly enhanced in the finite doping regime. The effective model in the strongly repulsive regime reveals that the attraction is mediated by the closed channel, in analogy to atomic Feshbach resonances between open and closed channels [2].

[1] Hirthe et al., Nature 2023
[2] Lange et al., arXiv:2309.15843, 2309.13040

Q 65.2 Fri 14:45 HS 1010

ARPES spectroscopy of an extended Majumdar-Ghosh model — •Simon M. Linsel[1,2], Nader Mostaan[1,2,3], Annabelle Bohrdt[2,4], and Fabian Grusdt[1,2] — [1]LMU Munich, Germany — [2]Munich Center for Quantum Science and Technology, Germany — [3]Université Libre de Bruxelles, Brussels, Belgium — [4]University of Regensburg, Germany

Experimental and numerical spectroscopy have revealed novel physics in anti-ferromagnets, in particular in frustrated and doped systems. The Majumdar-Ghosh (MG) model has an analytically known spin-disordered ground state of dimerized singlets as a result of magnetic frustration. Here we study the single-hole angle-resolved photoemission spectroscopy (ARPES) spectrum of an extended MG model, where we introduce a spin-density interaction that is experimentally accessible with ultracold molecules. We report a bound spinon-holon ground state and clear signatures of a spinon-holon molecule state and polarons in the ARPES spectrum at different magnetizations. We also apply a Chevy ansatz to gain analytical insights into the molecule spectrum. Our results provide new insights into the physics of dopants in frustrated t-J models.

Q 65.3 Fri 15:00 HS 1010

In-Situ Observation of Antibunching at the Single-Atom Level in a Continuous Fermi Gas — •Tim de Jongh, Maxime Dixmerias, Joris Verstraten, Cyprien Daix, Bruno Peaudecerf, and Tarik Yefsah — Laboratoire Kastler Brossel, Paris, France

Fermionic systems adhere to Pauli Exclusion, one of the most fundamental principles of quantum mechanics that prevents identical fermions from occupying the same quantum state. This leads to an antibunching of particles which manifests itself in density-density correlations and sub-Poissonian number fluctuations. Here we present the direct, in situ observation of antibunching at the single-atom level. Using a newly developed Lithium 6 quantum gas microscope devoted to the study of continuous many-body systems, we probe both the density correlations and number fluctuations in an ultracold two-dimensional, non-interacting Fermi Gas in continuous space. For these highly degenerate gases, we observe distinct antibunching behavior in the density correlations as well as a clear suppression of the number fluctuations in the gas. The ability to distinguish the quantum fluctuation (zero temperature) contribution and the thermal contribution, allows us to use the fluctuation-dissipation theorem to extract the temperature of these samples from the number fluctuations, offering a direct thermometry method for single-atom imaging techniques. These results represent the first application of a quantum gas microscope to a many-body system in continuous space and offer the perspective to probe strongly interacting Fermi gases in free space at an unprecedented length scale.

Q 65.4 Fri 15:15 HS 1010

Towards Probing Heat Transport in an Anharmonic Ion Chain — •Moritz Göb[1], Bo Deng[1], Lea Lautenbacher[2], Giovanni Spaventa[2], Daqing Wang[1,3], Martin B. Plenio[2], and Kilian Singer[1] — [1]Institut für Physik, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany — [2]Institut für Theoretische Physik und IQST, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany — [3]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Trapped ions are a versatile platform, which is well suited for probing thermodynamics down to a single atom [1]. We have indentified nonlinear dynamics that results in a Duffing-type resonance that can be used to improve sensing of very small forces [2]. Motivated by these results we present how the experimental setup has relevance in the context of resource theory and how the special features of the tapered ion trap can be exploited to implement a model system for heat transport [3].

[1] J. Roßnagel, S. T. Dawkins, K. N. Tolazzi, O. Abah, E. Lutz, F. Schmidt-Kaler, and K. Singer, A single-atom heat engine, Science 352, 325 (2016).
[2] B. Deng, M. Göb, B. A. Stickler, M. Masuhr, K. Singer, and D. Wang, Amplifying a zeptonewton force with a single-ion nonlinear oscillator, PRL 131, 153601 (2023).
[3] M. Lostaglio, An introductory review of the resource theory approach to thermodynamics, Rep. Prog. Phys. 82 114001 (2019).

Q 65.5 Fri 15:30 HS 1010

Optimal time-dependent manipulation of Bose-Einstein condensates — •Timothé Estrampes[1,2], Alexander Herbst[1], Annie Pichery[1,2], Gabriel Müller[1], Dennis Schlippert[1], Ernst M. Rasel[1], Éric Charron[2], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Institut für Quantenoptik, Germany — [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France

Quantum sensing experiments benefit from fast Bose-Einstein Condensate (BEC) generation with small expansion energies. Here, we theoretically find the optimal BEC collimation parameters with painted optical potentials to experimentally achieve 2D expansion energies of 438(77) pK taking advantage of the tunable interactions by driving Feshbach resonances and engineering the collective oscillations. Based on these findings and corresponding simulations, we propose a scenario to realize 3D expansion energies on ground below 16 pK, going beyond the experimental state of the art in microgravity [A. Herbst et al., arXiv:2310.04383 (2023)].

Furthermore, we report on current theoretical studies of the dynamics of space single- and dual-BEC experiments including applications in NASA's Cold Atom Lab aboard the International Space Station or the sounding rocket mission MAIUS-2, paving the way for next-generation quantum sensing experiments, including tests of fundamental physics such as Einstein's equivalence principle.

This work is supported by the "ADI 2022" project funded by the IDEX Paris-Saclay, ANR-1-IDEX-0003-02 and the DLR with funds provided by the BMWi under Grant No. CAL-II 50WM2245A/B.

Q 65.6 Fri 15:45 HS 1010

Magnetic polarons beyond linear spin-wave theory: Mesons dressed by magnons — •Pit Bermes and Fabian Grusdt — LMU Munich & MCQST, Munich, Germany

When a mobile impurity is doped into an antiferromagnet, its movement will distort the surrounding magnetic order and yield a magnetic polaron. The resulting complex interplay of spin and charge degrees of freedom gives rise to very rich physics and is widely believed to be at the heart of high-temperature superconductivity in cuprates. Recent experimental realizations of the doped Fermi-Hubbard model in ultra-cold quantum gases allowed to probe the local structure of the polarons. Drawing from experimental insights, we present a new quantitative theoretical formalism to describe these quasiparticles in the strong coupling regime. Based on the phenomenological parton description and geometric string picture, we construct an effective Hamiltonian with weak coupling to the spin-wave excitations in the background, making the use of standard polaronic methods possible.

We apply our formalism to calculate beyond linear spin-wave spectra, analyze the pseudogap expected at low doping and resolve the difference between hole an electron doping on local correlations.

Q 65.7 Fri 16:00 HS 1010

A fluid of 10 ultracold fermions — •Lars Helge Heyen[1], Giuliano Giacalone[1], and Stefan Floerchinger[2] — [1]Universität Heidelberg, Deutschland — [2]Friedrich-Schiller-Universität Jena, Deutschland

Recent experiments in heavy-ion collisions have challenged our understanding of the applicability of fluid dynamics by showing typical signatures of collective flow with only a small number of final state particles. Motivated by this, we investigate fluidlike behavior in a system of few ultracold fermions. Our key observable is the inversion of the shape of the cloud after release from an anisotropic harmonic trap. This elliptic flow is shown to persist down to as low as 10 particles. I discuss ongoing efforts to understand these experimental observations.

Q 65.8 Fri 16:15 HS 1010

Anisotropic and Non-Additive Interactions of Rydberg Impurities in Bose-Einstein Condensates — •Aileen A.T. Durst[1,2], Seth T. Rittenhouse[3,2], Hossein R. Sadeghpour[2], and Matthew T. Eiles[1] — [1]Max-Planck-Institute for the Physics of Complex Systems, Germany — [2]ITAMP, Harvard & Smithsonian, USA — [3]United States Naval Academy, USA

The interaction between a highly electronically excited atomic impurity and surrounding BEC atoms is typically characterised by a scattering length which can rival or even surpass the average interparticle spacing. The significance of this interaction depends on the density: when the average distance between Bosons is smaller than the scattering length, the system exhibits a rich absorption spectrum which extends typical polaron physics. However, within a dense bath, the absorption spectrum consists only of a single broad Gaussian, indicating an almost classical response. The scattering length and interaction strength of a Rydberg impurity can be altered by changing the principal quantum number. Additionally, the electronic angular momentum of the impurity can be changed in order to control the nature of the interaction potential, which becomes anisotropic when the spherical symmetry is broken. In free space, this manipulation leads to the emergence of (2l+1) degenerate electronic potential energy surfaces, introducing additionally non-additive interactions. Our investigation delves into the impact of these non-additive and anisotropic interactions on the absorption spectrum of a Rydberg impurity within an ideal BEC.

Q 66: Precision Spectroscopy of Atoms and Ions V / Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)

Time: Friday 14:30–16:30 Location: HS 1098

Q 66.1 Fri 14:30 HS 1098

Laser Spectroscopy of Californium-253,254 — •Sebastian Berndt for the Fermium-Collaboration — Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany

Laser resonance ionization spectroscopy (RIS) is an efficient and element-sensitive technique to study the atomic and nuclear structure of transuranium elements. We present recent activities at the RISIKO mass separator at Johannes Gutenberg University Mainz (JGU) regarding laser spectroscopy of the exotic isotopes ^{253,254}Cf. Here, theoretical predictions point to a relevant role of ^{254}Cf in kilonova events associated with r-process nucleosynthesis in the cosmos. For this study, targets of $^{244-248}$Cm were neutron-irradiated at the High Flux Isotope Reactor, Oak Ridge National Laboratory (ORNL) to breed ^{253,254}Es, which was chemically separated at ORNL's Radiochemical Engineering Development Center. This sample was shipped to JGU via Florida State University and then sent to Institut Laue-Langevin for a second irradiation with thermal neutrons to produce ^{255}Es (39.8 d). As the sample also contained about 10^9 atoms of ^{252}Cf, this was in addition transmuted to ^{253,254}Cf. The hyperfine structure of the 420 nm ground state transition in ^{253}Cf as well as the isotope shift of ^{254}Cf in the 417 nm and 420 nm ground-state transitions were investigated with high resolution RIS, giving access to the nuclear ground-state properties.

Q 66.2 Fri 14:45 HS 1098

Laser-induced population transfer in $^{25}Mg^+$ at the CRYRING@ESR storage ring — •Konstantin Mohr for the STOA-Collaboration — Institut für Kernphysik, TU Darmstadt, Germany

At the magnetic storage ring CRYRING@ESR located at the GSI facility for heavy ion research the laser spectroscopy experiment is performed on $^{25}Mg^+$ to investigate the interplay between internal and external degrees of freedom, i.e. quantum states and particle momenta.

Particular interest is devoted to the question whether it is possible to achieve and maintain a nuclear polarization of $^{25}Mg^+$ by optical pumping within the magnetic manifold of the hyperfine structure. This was studied with an electron-cooled coasting ion beam as well as in bunched beam operation at energies of about 155keV/u. In bunched-beam operation, it turned out that both the laser-induced spontaneous force and the varying velocity of the ions due to synchrotron oscillations need to be considered in order to explain the subtleties of the resonance shape.

We present our recent results and discuss the dynamic behavior of both modes of operation.

We acknowledge support from the BMBF under contract numbers 05P21RDFA1 and 05P19PMFA1, and from the DFG–Project-Id 279384907–SFB 1245.

Q 66.3 Fri 15:00 HS 1098

Stopping mass-selected alkaline-earth metal monofluoride beams via formation of unusually stable anions — •Konstantin Gaul[1], Ronald F. Garcia Ruiz[2], and Robert Berger[1] — [1]Fachbereich Chemie, Philipps-Universität Marburg,Hans-Meerweinstraße 4, 35032 Marburg, Germany — [2]Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Direct laser-coolability and a comparatively simple electronic structure render alkaline-earth metal monofluoride molecules (MF), versatile laboratories for precision tests of fundamental physics. In this theoretical work, prospects for efficient stopping and cooling of hot beams of mass-selected MF molecules via their anions are explored. With sophisticated quantum chemical methods it is shown that these molecular anions posses an unusually strong chemical bond and have favourable photo-electron detachment energies. For RaF^- a vibronic structure with favorable properties for efficient pre-cooling is identified. This study indicates even chances for direct laser-cooling of the anion.

Q 66.4 Fri 15:15 HS 1098

Precise Temperature Characterization of Project 8's Atomic Hydrogen Source — •Brunilda Muçogllava and Martin Fertl for the Project 8-Collaboration — Johannes Gutenberg Universität Mainz

In order to achieve a neutrino mass sensitivity of 40 meV, the Project 8 experiment aims to use the Cyclotron Radiation Emission Spectroscopy technique to analyze the atomic tritium beta decay spectrum. Due to the radioactive nature of tritium, initial measurements have been carried out using a Hydrogen Atom Beam Source (HABS) at the Mainz atomic test stand. Molecular hydrogen is introduced into the HABS setup, flowing through a 1 mm diameter tungsten capillary which is radiatively heated to ~2300 K by a tungsten filament. This causes the molecules to thermally dissociate in a temperature-dependent way. Accurate capillary temperature measurements with low uncertainty at these high temperatures are required to characterize the source accurately and understand the dissociation efficiency from molecular to atomic hydrogen. This talk will present infrared spectroscopy measurement results of the capillary, addressing challenges arising from uncertain emissivity values, ultra-high vacuum conditions, and device-dependent absolute calibration.

Q 66.5 Fri 15:30 HS 1098

Quantum Gate Optimization for Rydberg Architectures

in the Weak-Coupling Limit — •Nicolas Heimann[1,2,3], Lukas Broers[1,2], Nejira Pintul[1,2], Tobias Petersen[1,2], Koen Sponselee[1,2], Alexander Ilin[1,2,3], Christoph Becker[1,2], and Ludwig Mathey[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

We demonstrate machine learning assisted design of a two-qubit gate in a Rydberg tweezer system. Two low-energy hyperfine states in each of the atoms represent the logical qubit and a Rydberg state acts as an auxiliary state to induce qubit interaction. Utilizing a hybrid quantum-classical optimizer, we generate optimal pulse sequences that implement a CNOT gate with high fidelity, for experimentally realistic parameters and protocols, as well as realistic limitations. We show that local control of single qubit operations is sufficient for performing quantum computation on a large array of atoms. We generate optimized strategies that are robust for both the strong-coupling, blockade regime of the Rydberg states, but also for the weak-coupling limit. Thus, we show that Rydberg-based quantum information processing in the weak-coupling limit is a desirable approach, being robust and optimal, with current technology.

Q 66.6 Fri 15:45 HS 1098

FRESNEL: Engineering a Neutral Atom Quantum Computer
— •Guillaume Villaret for the FRESNEL-Collaboration — Pasqal SAS, 7 Rue Léonard de Vinci, 91300 Massy, France

Based on the work from the group of A. Browaeys and T. Lahaye at Institut d'Optique, quantum startup PASQAL developed and produced a first generation of commercial QPUs called FRESNEL. These devices allow analogical computations on arrays of up to 100 Rydberg atoms. Interfaced through a cloud access, these QPUs already proved their reliability. They allowed quantum software engineers to propose and demonstrate applications for solving hard combinatorial optimisation problems, non-linear differential equations and classifying sets of graphs using machine learning. Some of these QPUs are currently under construction in two HPC centers in Jülich, Germany and in Bruyères-le-Châtel, France. This represents a big step forward in term of reliability for neutral atoms QPUs, and more generally for cold atoms technologies which require a high level of engineering. We will give an overview of the technical building blocks of the FRESNEL products, discuss its capabilities for analog-based quantum computing in the NISQ era, and present the latest results.

Q 66.7 Fri 16:00 HS 1098

NON-ADIABATIC COUPLINGS AS A STABILIZATION MECHANISM IN LONG-RANGE RYDBERG MOLECULES
— AILEEN DURST, •MILENA SIMIĆ, NEETHU ABRAHAM, and MATTHEW EILES — Max-Planck-Institut for The Physics of Complex Systems, Dresden, Germany

The electronic potential curves of long-range Rydberg molecules composed of a Rydberg atom and a ground-state atom possess several distinctive features, including oscillations as a function of internuclear distance and, for an alkaline ground state atom, a steep drop when the electron-atom scattering interaction becomes resonant. This latter feature is accompanied by a narrow avoided crossing between potential energy curves, which implies that non-adiabatic couplings could become significant very close to the position of this rapid change in the potential curve. When these couplings are sufficiently strong, they can stabilize the molecule by shielding the vibrational states from the steep drop and possible decay. To demonstrate the importance of the non-adiabatic couplings in a rubidium Rydberg molecule, we compare the binding energies and lifetimes of the vibrational states obtained in the Born Oppenheimer approximation with those including beyond-Born Oppenheimer effects.

Q 66.8 Fri 16:15 HS 1098

Quantum Optimization of Two-Qubit Gate of Neutral Rydberg Atoms
— •Aslam Parvej[1,2], Nicolas Heimann[1,2], Lukas Broers[1,2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany

The fundamental cause of error for the high-fidelity gates in the quantum computing architectures of neutral atoms in optical tweezer arrays is the unwanted entanglement of motional excitations in the tweezer traps. We study the machine learning aided neutral Rydberg atoms in the weakly-interacting regime of two Rydberg atoms, with van der Walls interaction to implement a high-fidelity two-qubit controlled-Z gate while returning to the system to its motional ground states and generates an optimized pulse using hybrid quantum-classical optimizer. In the set up, the Rydberg state is coupled with logical qubit via global Rabi pulse and the motional degrees of freedom inside optical tweezers is coupled with each Rydberg atom.

Q 67: Machine Learning

Time: Friday 14:30–16:30 Location: Aula

Invited Talk Q 67.1 Fri 14:30 Aula

Towards an Artificial Muse for new Ideas in Quantum Physics
— •Mario Krenn — Max Planck Institute for the Science of Light, Erlangen, Germany

Artificial intelligence (AI) is a potentially disruptive tool for physics and science in general. One crucial question is how this technology can contribute at a conceptual level to help acquire new scientific understanding or inspire new surprising ideas. I will talk about how AI can be used as an artificial muse in quantum physics, which suggests surprising and unconventional ideas and techniques that the human scientist can interpret, understand and generalize to its fullest potential.

[1] Krenn, Kottmann, Tischler, Aspuru-Guzik, Conceptual understanding through efficient automated design of quantum optical experiments. Physical Review X 11(3), 031044 (2021).

[2] Krenn, Pollice, Guo, Aldeghi, Cervera-Lierta, Friederich, Gomes, Häse, Jinich, Nigam, Yao, Aspuru-Guzik, On scientific understanding with artificial intelligence. Nature Reviews Physics 4, 761 (2022).

[3] Krenn, et al., Forecasting the future of artificial intelligence with machine learning-based link prediction in an exponentially growing knowledge network. Nature Machine Intelligence 5, 1326 (2023).

Q 67.2 Fri 15:00 Aula

Artificial Intelligence for Quantum Sensing
— •Victor Jose Martinez Lahuerta, Jan-Niclas Kirsten-Siemss, and Naceur Gaaloul — Leibniz University Hannover, Institut of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany

Algorithms from the field of artificial intelligence (AI) and machine learning have been employed in recent years for a variety of applications to efficiently solve multidimensional problems. In physics, these algorithms are applied with increasing success, for example, to solve the Schrödinger equation for many-body problems, or used experimentally to generate ultracold atoms and control lasers. In this project we aim to work on three fundamental pillars of AI in atom interferometry: theory modeling, measurement data extraction, and operation of experiments. Within this context, I will talk about our results modeling a diffraction phase-free Bragg atom interferometry.

Acknowledgements: This project is funded by the German Space Agency (DLR) with funds provided by the German Federal Ministry of Economic Affairs and Energy (German Federal Ministry of Education and Research (BMBF)) due to an enactment of the German Bundestag under Grant No. DLR 50WM2253A

Q 67.3 Fri 15:15 Aula

Optimizing the active isolation of an optical table with machine learning
— •Jan-Niklas Feldhusen, Artem Basalaev, and Oliver Gerberding — Institut für Experimentalphysik, Universität Hamburg, 22761 Hamburg, Germany

Environmental seismic disturbances, also called seismic noise, limit the sensitivity of ground based gravitational wave detectors.

These disturbances couple via the optical components into the signal. To mitigate this noise, the optical components are passively isolated with suspensions. Parts of the suspension system include an active isolation, which suppresses the inflicted movement by knowing the transfer function of the suspension system and the motion on the ground.

We study if it is possible to improve the active isolation with an artificial neural network. In our laboratory at Universität Hamburg we have a large vacuum chamber with a seismically isolated optical table inside, intended for in-vacuum testing of interferometric inertial sensors - a task that has qualitatively similar requirements for seismic isolation as the first isolation stages of gravitational wave detectors. In this study we show that it is possible to infer averaged spectral density of motion of the table from measurements with seismometers on the floor, by utilizing artificial neural networks. We can get a better estimate of the seismic noise spectral amplitudes on the optical table than a Wiener Filter. We also investigate the ability of the neural network to predict future motion to get a real-time active isolation by feedforward of the inverted anticipated motion.

Q 67.4 Fri 15:30 Aula

Evalutation of machine learning algorithms for applications in quantum gas experiments — •Oliver Anton[1], Victoria Henderson[1], Elisa Da Ros[1], Philipp-Immanuel Schneider[3,4], Ivan Sekulic[3,4], Sven Burger[3,4], and Markus Krutzik[1,2] — [1]Institut für Physik and IRIS, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]JCMwave GmbH, Berlin — [4]Zuse Institute Berlin (ZIB), Berlin

The generation of clouds containing cold and ultra-cold atoms is a complex process that requires the optimization of noisy data in multi dimensional parameter spaces. Optimization of this problem can present challenges both in and outside of the lab due to constrains in time, expertise, or access for lengthy manual optimization.
Machine learning offers a solution thanks to its ability to efficiently optimize high dimensional problems without the need for knowledge of the experiment itself. In this presentation, we show the results of benchmarking various optimization algorithms and implementations, testing their performance in real-world experiment, subjected to inherent noise. This work is partially supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Climate Action (BMWK) under grant numbers No. 50WM2067, 50WM2175 and 50WM2247.

Q 67.5 Fri 15:45 Aula

Machine learning optimal control pulses in an optical quantum memory — •Elizabeth Robertson[1], Luisa Esguerra[1,2], Leon Messner[1], Guillermo Gallego[3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Rutherfordstr. 2, 12489 Berlin, Germany — [2]Technische Universiät Berlin, Institute for Optics and Atomic Physics, Hardenbergstr. 36, 10623 Berlin, Germany — [3]Einstein Center Digital Future and Science of Intelligence Excellence Cluster 10117 Berlin, Germany

Efficient optical quantum memories are a milestone required for several quantum technologies including repeater-based quantum key distribution and on-demand multi-photon generation [1,2]. We present an optimization of the storage efficiency of an optical electromagnetically induced transparency (EIT) memory experiment in a warm cesium vapor using a genetic algorithm to update the control laser waveform. The write pulse is represented either as a Gaussian or free-form pulse, and the results from the optimization are analyzed and compared. We find that the free-form pulses offer a 3%(7) improvement in efficiency, over the learned Gaussian. By limiting the allowed pulse power in a solution, we show a power-based optimization giving a 30% reduction in power, with minimal efficiency loss.

[1] M. Gündoğan et al., Topical white paper: A case for quantum memories in space (2021), arXiv:2111.09595 [2] J. Nunn et al., Multimode memories in atomic ensembles, Physical Review Letters 101, 260502 (2008).

Q 67.6 Fri 16:00 Aula

Bayesian Optimization for Robust State Preparation in Quantum Many-Body Systems — •Tizian Blatz[1,2] and Annabelle Bohrdt[2,3] — [1]Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]University of Regensburg, Regensburg, Germany

New generations of ultracold atom experiments are continually raising the demand for efficient solutions to optimal control problems. We present a Bayesian-optimization approach to improve a state- preparation protocol recently implemented in an ultracold-atom experiment to realize a two-particle fractional quantum Hall state. Compared to manual ramp design, we demonstrate the superior performance of our optimization approach in a numerical simulation, resulting in a protocol that is faster by an order of magnitude at the same fidelity, even when taking into account experimentally realistic levels of disorder in the system. We extensively analyze and discuss questions of robustness and the relationship between numerical simulation and experimental realization, and how to make the best use of the surrogate model trained during optimization. We find that numerical simulation can be expected to substantially reduce the number of experiments that need to be performed with even the most basic transfer learning techniques. The proposed protocol and workflow will pave the way toward the realization of more complex many-body quantum states in experiments.

Q 67.7 Fri 16:15 Aula

Entanglement certification for mixed quantum states prepared on noisy quantum hardware — •Andreas J. C. Woitzik[1], Eric Brunner[1,2], Jiheon Seong[3], Hyeokjae Kwon[3], Seungchan Seo[3], Joonwoo Bae[3], Andreas Buchleitner[1,4], and Edoardo Carnio[1,4] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg im Breisgau, Federal Republic of Germany — [2]Quantinuum, London, United Kingdom — [3]School of Electrical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Republic of (South) Korea — [4]EUCOR Centre for Quantum Science and Quantum Computing, Freiburg im Breisgau, Federal Republic of Germany

Entanglement is a fundamental aspect of quantum physics, conceptually, as well as for its many applications. Classifying a given mixed state as entangled or separable – a task referred to as the separability problem – poses a significant challenge, since a N-qubit state can be entangled with respect to many different partitions of the N qubits.

We have developed a classification method that feeds the statistics of random local measurements into a non-linear dimensionality reduction algorithm, to determine with respect to which partitions a given quantum state is entangled. After training a model on randomly generated quantum states with different entanglement structures, and of varying purity, we verify the accuracy of its predictions on synthetic test data, and finally apply it to states prepared on IBM quantum computing hardware.

Q 68: Quantum Computing and Simulation II

Time: Friday 14:30–16:30 Location: HS 1199

Q 68.1 Fri 14:30 HS 1199

Single atoms in a cavity: a platform for photonic graph states generation — Philip Thomas, Leonardo Ruscio, •Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Photonic graph states are powerful resources for numerous quantum information applications, from pure quantum computation, with so-called measurement based quantum computing (MBQC), to the one-way quantum repeater for quantum communication. However, generating graph states experimentally is a tremendous challenge. The cavity QED toolbox offers all that is needed to efficiently generate graph states. Using a single atom in an optical cavity we have shown the generation record-size Greenberger-Horne-Zeilinger (GHZ) states and linear cluster states [1]. With only one photon emitter, the type of graph states one can generate remains limited though. Hence, to go beyond, we show that elementary graph states – generated by two independent atoms – can be fused into more complex graph states, such as ring states, used for error correction, and tree states for the one-way quantum repeater [2]. This concept can be extended to an even larger number of atoms, providing a universal platform. Hence, these demonstrations are moving forward the potential of graph states for realistic applications in quantum information.

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

[2] P. Thomas *et al.*, Under review (2024).

Q 68.2 Fri 14:45 HS 1199

Towards Photonic Cluster-State Generation — •Thomas Häffner, Siavash Qodratipour, and Oliver Benson — Nano-Optik, Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Deutschland

Fusion-based linear optical quantum computing (LOQC) is a promising platform, where the complexity is shifted from two-qubit gates to the generation of a resource state, a highly entangled cluster state [1]. As the goal is an integrated photonic implementation of such a quantum computer, our experiment is completely in optical fibers. Therefore a suitable choice for qubits is the time-bin degree of freedom of single photons. Time-bin entangled pairs of two single photons are generated in a type-II periodically-poled LiNbO3 waveguide by a pulsed laser source [2]. We show Hong-Ou-Mandel (HOM) interference between two photons of two subsequent time-multiplexed pairs. The visibility of the HOM interference is a measure of the pureness and indistinguishability of single photons, which are necessary to efficiently entangle photons into cluster states. Multi-pair generation decreases the visibility of the HOM interference. A time-multiplexed pseudo-photon-number-resolving detector was built and is used to optimize the probability of generating exactly one photon pair per pump pulse. Recent results of the experimental implementation towards a time-bin fusion gate will be presented. [1] Bartolucci, S. et al. Fusion-based quantum computation. Nat. Commun. 14, 912 (2023) [2] Montaut, N. et al. High-Efficiency Plug-and-Play Source of Heralded Single Photons. Phys. Rev. Applied 8, 024021 (2017)

Q 68.3 Fri 15:00 HS 1199

Entanglement Transfer Properties in Time-Multiplexed Discrete-Time Quantum Walks — •Jonas Lammers, Federico Pegoraro, Philip Held, Nidhin Prasannan, Fabian Schlue, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Entanglement, as it arises from quantum mechanics, is a powerful resource underlying many protocols demonstrating quantum advantage. Interestingly, the inseparability of multiple degrees of freedom underlying entanglement has a classical analog exhibited for example by coherent laser light. As this classical inseparability (aka. modal entanglement) cannot be used to violate local realism, it has a controversial role in the field of quantum information science. In this work, we contribute to this discussion by studying how modal entanglement interacts with quantum entanglement between two photons when subjecting one photon to a quantum walk evolution. For this purpose we generate two polarization entangled photons. One of which we send to a free-space time-multiplexed discrete-time quantum walk (QW). Here we investigate how the modal entanglement generated via the QW transfers multi-particle entanglement from the initial polarization-polarization towards the position-polarization encoding spanning both photons. For this purpose, we perform two photon polarization tomography at each individual position of the QW. We further developed an original measure which reveals signatures of multi-particle entanglement in conditioned position distributions.

Q 68.4 Fri 15:15 HS 1199

Implementation of a scalable quantum network node — •Matthias Seubert[1], Lukas Hartung[1], Stephan Welte[2], Emanuele Distante[1], and Gerhard Rempe[1] — [1]Max- Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching — [2]ETH Zürich, Otto-Stern-Weg 1, 8093 Zürich

For many envisioned applications of quantum networks, efficient and scalable quantum nodes are needed. A promising candidate are single neutral atoms trapped at the center of an optical resonator. While this architecture has proven its capabilities for storing and processing quantum information [1], probabilistic loading limits the number of individual controllable qubits to two. Optical tweezers by contrast, have demonstrated deterministic loading and a high degree of scalability [2].

In this talk, we show the merging of an optical cavity setup in the strong coupling regime with an optical tweezers setup. ^{87}Rb atoms are loaded at the center of a resonator and transferred into an optical tweezers array. Exploiting movable tweezers, individual atoms are rearranged in predefined atomic patterns with sub-wavelength precision. Afterwards we load the atoms into a 2D optical lattice. In this manner, we show a significant increase of preparing a deterministic number of simultaneously coupled atoms at predefined positions. Furthermore, we demonstrate the addressing capabilities of our setup by consecutively generating photons from individual atoms. In the future, this setup will be used to efficiently generate atom-photon entanglement.

[1] A. Reiserer and G. Rempe, Rev. Mod. Phys. 87, 1379 (2015)
[2] D. Barredo et al., Science 354, 6315 (2016)

Q 68.5 Fri 15:30 HS 1199

Robust quantum-network nodes through real-time noise mitigation — •Yang Wang[1,2], Sjoerd Loenen[2], Barbara Terhal[2,3], and Tim Taminiau[2] — [1]3. Physikalisches Institut, ZAQuant, University of Stuttgart, Allmandring 13, 70569 Stuttgart, Germany — [2]QuTech, Delft University of Technology, PO Box 5046, 2600 GA Delft, The Netherlands — [3]JARA Institute for Quantum Information, Forschungszentrum Juelich, D-52425 Juelich, Germany

The nitrogen-vacancy (NV) center in diamond and other solid-state defect centers hold great potential for constructing quantum networks. NV centers can be remotely connected through entanglement via photonic links. Furthermore, by utilizing the electronic spin of the NV center to control associated nuclear spins, a small multi-qubit register can be formed. However, reliably storing entangled states while generating new entanglement links poses a significant challenge when scaling towards large networks. In this study, we propose a method that utilizes spectator qubits to mitigate noise on stored quantum states in real time. We consider a single NV center with multiple nuclear-spin qubits, and some nuclear spins are selected as spectator qubits that are not entangled with other nuclear spins serving as data qubits. The spectator qubits are initialized in a phase-sensitive state, and measuring them after sequences of optical entanglement attempts allows us to infer the stochastic phases acquired by the data qubits without additional operations on them. The spectator qubit approach is flexible and simple, and our experiments demonstrate that spectator qubits may be a useful tool for realizing robust quantum-network nodes.

Q 68.6 Fri 15:45 HS 1199

Two-qubit encoding strategy for a continuous quantum system — •Sebastian Luhn and Matthias Zimmermann — DLR e.V., Institut für Quantentechnologien, Ulm

Bosonic codes employ particular states of an infinite-dimensional Hilbert space to encode a qubit within a continuous quantum system. Despite the enormous resources available in a continuous quantum system [1], typical encodings only exist for single qubits [2]. Here we go one step further and present an encoding for two qubits (four states), which protects against errors in the shift of the canonical variables q and p. Furthermore, we present possible implementations of common single and two-qubit operations, based on particular symmetry operations for continuous quantum states represented by a square lattice in phase space.

[1] Lloyd, S. and Braunstein, S. (1999). Quantum Computation over Continuous Variables Phys. Rev. Letters, Vol. 82, No. 8
[2] Gottesman, D., Kitaev, A., and Preskill, J. (2001). Encoding a qubit in an oscillator. Phys. Rev. A, 64:012310

Q 68.7 Fri 16:00 HS 1199

Programmable high-dimensional mode-sorting of time-frequency states of single photons — •Laura Serino, Abhinandan Bhattacharjee, Michael Stefszky, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

The time-frequency (TF) degree of freedom of single photons provides high-dimensional encoding alphabets that can enhance quantum information science by increasing the robustness and capacity of quantum information carriers. These alphabets are generally classified into frequency bins, time bins and temporal modes, each coming with its own unique challenges and advantages. Simultaneously manipulating or detecting multiple single-photon TF modes and their superpositions is a challenging task, and most experimental demonstrations rely on complex interferometric setups or on a combination of phase modulators and pulse shapers, which are bound to a specific encoding alphabet.

In this work, we present for the first time programmable high-dimensional mode-sorting of single-photon-level TF states, achieved through a multi-output quantum pulse gate (mQPG). We demonstrate high-fidelity simultaneous high-dimensional projections onto temporal modes, frequency bins and time bins, where the encoding alphabet is changed programmatically via pulse shaping. For each encoding alphabet, we demonstrate projections onto multiple superposition bases, paving the way for practical applications in quantum information science.

Q 68.8 Fri 16:15 HS 1199

Towards solving Computer Vision optimization problems on an ion-trap-based quantum computer — •Florian Köppen[1], Sebastian Becker[3], Marcel Seelbach Benkner[2], Michael Möller[2], and Christof Wunderlich[1] — [1]Dept. Physik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen, Germany — [2]Dept. Informatik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen, Germany — [3]Mathematisch-Naturwissenschaftliche Fakultät, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

Many problems in computer vision are optimization problems with quadratic cost functions - quadratic assignment problems (QAP) - which are NP-hard and are solved on classical computers by heuristics and relaxation algorithms. A QAP can be mapped onto an Ising-type Hamiltonian, which in turn could in principle be solved efficiently and exactly on a quantum computer by quantum annealing. With the help of magnetic gradient-induced coupling (MAGIC) between trapped ion-qubits, the long-range all-to-all interaction of the Ising Model is realized[1]. Here, we present an algorithm translating a QAP into the physical coupling between qubits and further into concrete parameter settings of a microstructured, segmented ion trap. This work is guided by using quantum annealing with trapped ions for solving pertinent problems in computer vision. [1] Pilz et al., Sci. Adv. 2 (7) 2016, e1600093

Q 69: Precision Measurements III (joint session Q/A)

Time: Friday 14:30–16:30 Location: HS 1221

Q 69.1 Fri 14:30 HS 1221

Coriolis bias estimation in the transportable Quantum Gravimeter QG-1 — •Pablo Nuñez von Voigt[1], Nina Heine[1], Najwa Al-Zaki[1], Waldemar Herr[2], Christian Schubert[2], Ludger Timmen[3], Jürgen Müller[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik, Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The Quantum Gravimeter QG-1 relies on the interferometric interrogation of magnetically collimated Bose-Einstein condensates (BEC) in a transportable setup. The falling BEC is detected via absorption imaging, allowing a better characterization of uncertainties of the motional degrees of freedom than fluorescence detection. The horizontal velocity component is utilized to estimate the uncertainty in the bias acceleration due to the Coriolis effect. Estimations from a gradiometer measurement are presented together with proposed measures to compensate for the Coriolis effect.

We acknowledge financial funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 69.2 Fri 14:45 HS 1221

Inertial sensing deploying painted optical potentials — •Knut Stolzenberg, Sebastian Bode, Christian Struckmann, Alexander Herbst, Daida Thomas, Naceur Gaaloul, Ernst Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Inertial sensors based on atom interferometers can become a viable addition to classical IMUs, e.g., for autonomous driving or aviation in GNSS-denied environments. While they are superior with respect to their accuracy and long-term stability, it remains challenging to simultaneously measure accelerations and rotations in one or more axes in present experiments. In our experiment a 1064 nm crossed optical dipole trap (ODT) is used for creation of quantum-degenerate ensembles. By using acousto-optical deflectors in both ODT beam paths, we add versatile control over the trapping potentials with respect to position and trap depth. This allows for the creation of BECs amounting to a total number of up to 300×10^3 ultracold ^{87}Rb atoms prepared in the magnetically insensitive state $F = 1, m_F = 0$. We report on prospects of implementing guided quantum inertial sensors by light-pulsed atom interferometry in waveguides and by atomtronics in painted potentials.

Q 69.3 Fri 15:00 HS 1221

Enhancing the sensitivity and dynamic range of atom interferometer measurements using an integrated opto-mechanical vibration sensor — •Ashwin Rajagopalan, Ernst M. Rasel, Sven Abend, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik,
Welfengarten 1, 30167 Hannover, Germany

The measurement sensitivity of an atom interferometer (AI) is predominantly impaired by vibrational noise, this is due to its slow measurement rate and relatively small dynamic range. As a first proof of principle, we demonstrated implementing a miniaturized AI compatible opto-mechanical accelerometer to a T = 10 ms AI which resolves measurement ambiguity and measures the local gravitational acceleration with an uncertainty of 4×10^{-6} ms^{-2} after an integration time of 18000 seconds without any vibration isolation. We are now in preparation to implement the next enhanced version of the opto-mechanical accelerometer which is fully integrated with the retro-reflection mirror of the AI, such that the AI and accelerometer share a common inertial reference. This new accelerometer incorporates a Fabry Pérot interferometer with a mirror reflectivity of 99.9 percent for highly sensitive read-out. An efficient vibrational signal read-out scheme has been implemented and first correlation with a state of the art commercial accelerometer has been observed even at sub-Hertz frequencies.

Funded by the DFG EXC2123 QuantumFrontiers - 390837967 supported by the DLR with funds provided by BMWK under Grant No. DLR 50NA2106 (QGyro+) and DFG SFB 1464 TerraQ.

Q 69.4 Fri 15:15 HS 1221

Towards compact and field deployable quantum sensors for inertial navigation — •Ann Sabu[1], Polina Shelingovskaia[1], Yueyang Zou[1], Mouine Abidi[1], Philipp Barbey[1], Ashwin Rajagopalan[1], Christian Schubert[2], Matthias Gersemann[1], Dennis Schlippert[1], Ernst M. Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt

Quantum sensors using atom interferometry enable precise measurements of inertial forces with long-term stability. Highly sensitive and compact quantum sensors for field applications still pose a challenge.

In this talk, the progess of three experimental devices will be presented: a robust single-axis accelerometer for dynamic applications; a transportable multi-axis gyroscope; and a six-axis quantum sensor capable of measuring accelerations and rotations compatible for quantum navigation.

Telecom fiber laser systems are used for all the three devices. For the multi-axis gyroscope and the six-axis sensor, we exploit atom chip technology to create Bose-Einstein condensates for its low expansion rates. We also use a combination of twin-lattice and relaunch mechanisms to form multiple loops, providing a framework for both compact and large-area sensors along with large momentum transfer.

We acknowledge financial support by the DFG EXC2123 QuantumFrontiers - 390837967 and by the DLR with funds provided by BMWK under Grant No. DLR 50NA2106 (QGyro+).

Q 69.5 Fri 15:30 HS 1221

Optically guided BEC interferometry with a single wavelength — •Simon Kanthak[1], Rui Li[2], Ekim Hanimeli[3], Mikhail Cheredinov[2], Matthias Gersemann[2], Sven Herrmann[3], Naceur Gaaloul[2], Sven Abend[2], Ernst M. Rasel[2], Markus Krutzik[1], and the QUANTUS team[1,2,3,4,5] — [1]Institut für Physik, HU Berlin — [2]Institut für Quantenoptik, LU Hannover — [3]ZARM, Universität Bremen — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt

Precision sensing with Bose-Einstein condensates (BECs) has been achieved in macroscopic interferometers with underlying large scale enclosed space-time areas. As an alternative approach, trapped atom systems offer the opportunity for BEC sensors in more compact packages. This requires an optical guide, crossed beams and beam splitters usually operated at different wavelengths.

We report on an optically guided BEC interferometer operated with a single wavelength. To this end, atoms are first Bose condensed and delta-kick collimated using the magnetic potentials supplied by an atom chip. A single far-detuned focused beam in a linear retro-reflector configuration then provides both the tools to levitate as well as symmetrically split and recombine the matter-wave packets to form a guided Mach-Zehnder type atom interferometer.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant number DLR 50WM2250B (QUANTUS+).

Q 69.6 Fri 15:45 HS 1221

First experiments in the Hannover Very Long Baseline Atom Interferometer facility — •Vishu Gupta[1], Kai Grensemann[1], Dorothee Tell[1], Ali Lezeik[1], Mario Montero[1], Jonas Klussmeyer[1], Klaus Zipfel[1], Christian Schubert[1,2], Ernst Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodasie und Inertialsensorik

The gravitational acceleration of freely falling atoms can be measured accurately by tracking their movement with vertical lattices of light in a matter-wave interferometer scheme. The Very Long Baseline Atom Interferometry (VLBAI) facility at the Hannover institute of technology allows for highly accurate inertial measurements with applications ranging from fundamental physics to geodesy. The 10 m baseline facility with Bose-Einstein Condensates (BECs) and high performance seismic attenuation system (SAS) raises great potential for absolute gravimeter. In the Hannover VLBAI facility, rubidium BECs will be launched into the 10 m baseline to perform interferometery based on Bragg momentum transfer. Here we present the recent development of the VLBAI facility. To this point the installation of the Hannover VLBAI facility is complete with the Bragg interferomtery laser system, an all-optical source of rubidium BEC and high-performance in-vacuum SAS. We demonstrate the current status of the all optical Rb-BEC source, first steps for passive vibration isolation using an SAS and the necessary methods such as matter-wave lenses and Bragg beam splitters for first inertial measurements.

Q 69.7 Fri 16:00 HS 1221

Probe thermometry with continuous measurements — •Julia Boeyens[1], Björn Annby-Andersson[2], Pharnam Bakhshinezhad[2,3], Géraldine Haack[4], Martí Perarnau-Llobet[4], Stefan Nimmrichter[1], Patrick P. Potts[5], and Mohammad Mehboudi[3,4] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen 57068, Germany — [2]Physics Department and NanoLund, Lund University, Box 118, 22100 Lund, Sweden — [3]Technische Universität Wien, Stadionallee 2, 1020 Vienna, Austria — [4]Département de Physique Appliquée, Université de Genève, 1211 Genève, Switzerland — [5]Department of Physics, University of Basel and Swiss Nanoscience Institute, Klingelbergstrasse 82, 4056 Basel, Switzerland

Accurate thermometry plays a vital role in natural sciences. A well studied approach is to prepare a probe and allow it to interact with a thermal environment of unknown temperature for a fixed time before being measured. However, in some experimentally relevant settings, it is more practical to allow the probe to interact continuously with the environment. We consider a minimal model consisting of a two-level probe coupled to the thermal environment. Monitoring thermal transitions enables real-time estimation of temperature. We discuss adaptive and non-adaptive strategies. In particular, we evaluate the Fisher information for the trajectories of the probe and optimise according to this. Finally, we investigate the performance of the thermometer when the measurements made are subject to noise. This lays the foundation for experimentally realised real-time adaptive thermometry.

Q 69.8 Fri 16:15 HS 1221

Sideband Thermometry on Ion Crystals — •Ivan Vybornyi[1], Laura Dreissen[2,3], Dominik Kiesenhofer[4,5], Helene Hainzer[4,5], Matthias Bock[4,5], Tuomas Ollikainen[4,5], Daniel Vadlejch[2], Christian Roos[4,5], Tanja Mehlstäubler[2,6], and Klemens Hammerer[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany — [3]Department of Physics and Astronomy, LaserLab, Vrije Universiteit, De Boeleaan, 1081 HV Amsterdam, The Netherlands — [4]Universität Innsbruck, Institut für Experimentalphysik, Technikerstraße 25, 6020 Innsbruck, Austria — [5]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, 6020 Innsbruck, Austria — [6]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Coulomb crystals of cold trapped ions are a leading platform for quantum computing, simulations and metrology. For these applications, it is essential to be able to determine the crystal's temperature with high accuracy, which is a challenging task for large crystals due to complex many-body correlations. Recently [arXiv:2306.07880v3] we presented an ion crystal thermometry method that deals with this problem. With two experiments (4 ions 1D linear chain and 19 ions 2D crystal) we test the new method and cross-check it via other techniques. The results confirm the new method being accurate and efficient. Current work aims to generalize ion thermometry for non-thermal states of motion.

Q 70: Quantum Optics

Time: Friday 14:30–16:15 Location: HS 3118

Q 70.1 Fri 14:30 HS 3118

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

Bose-Einstein condensation can be observed with e.g. ultracold atomic gases, polaritons and since about a decade ago also with low-dimensional photon gases [1]. In recent work with photon gases direct condensation into a coherently split state of light has been realized [2]. Here we report on experimental work directed at realizing thermalized photon gases in periodic potentials of increased complexity, i.e. beyond a double well.

Our experiments use a controlled mirror surface delamination technique to imprint four micro-wells arranged in a ring giving rise to a hybridized ground state for the photon gas [3]. This ring of micro-wells is enclosed by a spherically curved potential providing a manifold of harmonically spaced oscillator levels.

We observe macroscopic accumulation of photons in the ground state when reaching the condensation threshold and the measured spectral photon distribution closely follows a room temperature Bose-Einstein distribution. Using an optical interferometer we probe for the relative phase relation of the emission of the microsites, revealing the relative coherence between the four wells.

[1] J. Klaers et al., Nature 468, 545-548 (2010)
[2] C. Kurtscheid et al., Science 366, 894-897 (2019)
[3] C. Kurtscheid et al., EPL 130, 54001 (2020)

Q 70.2 Fri 14:45 HS 3118

Degenerate Cavity for Dispersive Imaging of Ultracold Atoms — •Oliver Lueghamer[1], Thomas Juffmann[2,3], and Maximilian Prüfer[1] — [1]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien — [2]University of Vienna, Faculty of Physics, VCQ — [3]University of Vienna, Max Perutz Laboratories, Department of Structural and Computational Biology

Dispersive imaging is routinely used in cold atom experiments. However the quantum limited operation is still a challenge. We present an approach using a degenerate cavity, which allows the probe beam to pass the sample multiple times. Degenerate cavities were already used in quantum microscopy to surpass the shot noise limit without the use of delicate quantum states. For this mostly biological investigations, a pulsed laser operation was employed. Only recently continuous wave applications were implemented experimentally.

We develop and test such a degenerate cavity setup for the potential use in a consisting atom chip experiment. We are able to show a signal to noise ratio (SNR) enhancement for large biological samples (e.g. epithelial cells of a human cheek). We investigate the possibility of quickly driving the input mirror over the free spectral range to have enhancement without stabilizing the cavity. We conclude by giving an outlook on the possibility to use this technique for ultracold atom experiments.

Q 70.3 Fri 15:00 HS 3118

Rb-Xe Magnetometer - Quantum Memory Based on Rare Gases — •Denis Uhland[1], Luisa Esguerra[2,4], Norman Vincenz Ewald[2,3], Tianhao Liu[3], Wolfgang Kilian[3], Jens Voigt[3], Janik Wolters[2,4], and Ilja Gerhardt[1] — [1]Leibniz University Hannover, Institute of Solid State Physics, Light and Matter Group, Hannover — [2]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin — [3]Physikalisch-Technische Bundesanstalt, FB 8.2 Biosignale, Berlin — [4]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin

Optical quantum memories allow for the storage and retrieval of quantum information. A common approach to establish such memories is to map the photonic state onto optically accessible matter states. Even longer storage can be realized with rare gases, but unfortunately, they lack convenient optical access, which seemingly can be overcome [1]. Due to spin-exchange collisions arising from a polarized ensemble of alkali atoms, it is possible to transfer photonic states onto optical inaccessible spin states of the nucleus of rare gases. That results in an increase of the memory time from milliseconds seen in alkali vapors to several minutes or even hours [2]. A recent achievement uses ^{133}Cs as an optical interface for photons stored in collective spin excitation via EIT [3]. Here, we present our first steps toward quantum memories based on an Rb-^{129}Xe mixture in a magnetically shielded environment.

[1] O. Katz et al., Phys. Rev. A (2022) 105, 042606
[2] C. Gemmel et al., Eur. Phys. J. D (2010) 57, 303
[3] L. Esguerra et al., Phys. Rev. A (2023) 107, 042607

Q 70.4 Fri 15:15 HS 3118

Proposal for an experimental demonstration of unforgeable quantum tokens in a room-temperature atomic memory — •Luisa Esguerra[1,2], Elizabeth Robertson[1,2], Helen Chrzanowski[1], Inna Kviatkovski[3,1], Leon Messner[1], Norman Vincenz Ewald[1,4], Mathieu Bozzio[5], and Janik Wolters[1,2] — [1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin — [2]TU Berlin, Institut für Optik und Atomare Physik — [3]TU Berlin, Institut für Luft und Raumfahrt — [4]Physikalisch-Technische Bundesanstalt, FB 8.2 Biosignale, Berlin — [5]University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ)

Alkali vapor cell quantum memories offer a simple platform for a plethora of applications in quantum information technologies. In this context, the efficient and low-noise storage of quantum tokens for authentication purposes remains an outstanding challenge. Inspired by a proposal for quantum money [1,2], we develop a quantum-token protocol based on a time-bin encoding, and use the memory system presented in [3] as a test platform for secure storage of the quantum token. This constitutes an important first step towards the realisation of authentification tokens secured by quantum mechanics.

[1] M. Bozzio et al., npj Quantum Inf 4, 5 (2018).
[2] M. Bozzio et al., Phys. Rev. A 99, 022336 (2019).
[3] L. Esguerra et al., Phys. Rev. A 107, 042607 (2023).

Q 70.5 Fri 15:30 HS 3118

Analytic Expressions of a closed-loop excitation scheme for phase-sensitive RF E-field sensing using Rydberg atom-based sensors — •Matthias Schmidt[1,2], Stephanie Bohaichuk[1], Vijin Venu[1], Florian Christaller[1], Chang Liu[1], Harald Kübler[1,2], and James P. Shaffer[1] — [1]Quantum Valley Ideas Laboratories, 485 Wes Graham Way, Waterloo, ON N2L 0A7, Canada — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

In this talk, we present theoretical work aimed at understanding radio frequency phase measurement using all-optical, atom-based electric field sensors. Atom-based radio frequency field sensors have a number of applications in communications, radar and test measurements. All of these applications benefit from being able to detect phase, which remains illusive for Rydberg atom-based sensors in the steady-state. To obtain an analytic expression for phase detection, we investigate closed-loop excitations in cesium that preserve phase information in a probe laser signal transmission coupled to one transition of the loop. Insight into the mechanisms that enable phase determination is gained by analyzing the close-loop processes. We find the highest sensitivity region by looking at the absorption contrast. The sensitivity maximizes when the atomic vapor is weakly probed. By applying the weak probe approximation to the Lindblad-master equation, we find an analytic expression for the absorption coefficient. With this expression, we gain a deeper understanding of the multi-photon interference and how this applies to phase readout in atom-based radio frequency sensors.

Q 70.6 Fri 15:45 HS 3118

Chiral Orbital States with Rydberg Atoms — •Stefan Aull[1], Steffen Giesen[2], Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Experimentalphysik 1, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Fachbereich Chemie, Philipps-Universität Marburg, Hans-Meerwein-Str. 4. 35032 Marburg — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

A protocol for the preparation of chiral orbital Rydberg states in atoms is presented. It has been shown theoretically that using a suitable superposition of hydrogen wave functions, it is possible to construct an electron density and probability current distribution that has chiral nature [1]. Circular Rydberg states can be generated and subsequently manipulated with tailored RF pulses under the influence of electric and magnetic fields, so that the desired chiral superposition of hydrogen-like states with corresponding phases can be prepared. A method to produce such Rydberg states is outlined and their properties including time evolution are discussed. Necessary conditions for quantum numbers of superposition states have been derived analytically. The results are aimed to be used for chiral discrimination [2] of molecules.

[1] A. F. Ordonez and O. Smirnova, Propensity rules in photoelectron circular dichroism in chiral molecules. I. Chiral hydrogen, Phys. Rev. A, vol. 99, no. 4, p. 43416 (2019)
[2] S. Y. Buhmann et al., Quantum sensing protocol for motionally chiral Rydberg atoms, New Journal of Physics, vol. 23, no. 8, Art. no. 8, (2021)

Q 70.7 Fri 16:00 HS 3118

Chiral sensing with nanophotonics — •Diana Shakirova, Adrià Canós Valero, and Thomas Weiss — Institute of Physics, University of Graz, Universitaetsplatz 5, 8010 Graz, Austria

Chirality is a geometrical property whereby the mirror image of an object does not coincide with the object itself. The handedness (left or right orientation in space) of chiral molecules can define its action on living organisms, making chiral sensing a crucial task in biology, chemistry and medicine. The difference in transmission (DT) between left- and right-handed circularly polarized incident light is used as a sensing measure, but this signal is extremely small. Nanophotonics provides a great potential for enhancing DT using resonances maintained by nanostructures in optical frequency range. In the work we discuss a theory of chiral light-matter interaction, general approaches to enhance DT,and present particular nanostructures for chiral sensing that support high-Q modes.

Q 71: Nano-Optics

Time: Friday 14:30–16:30 Location: HS 3219

Q 71.1 Fri 14:30 HS 3219

Near-field Fano spectroscopy of MaPbI3 nanoparticles — Jinxin Zhan[1], •Tom Jehle[1], Sven Stephan[1], Sam Nochowitz[1], Petra Gross[1], Ekaterina Tiguntseva[2], Sergey Makarov[2], and Christoph Lienau[1] — [1]Universität Oldenburg, Germany — [2]St. Petersburg, Russia

Dielectric nanoparticles particles have optical shape resonances that confine light on the nanoscale in localized modes with well-defined spatial field profiles. A particularly interesting example are halide perovskite nanoparticles, for which the coupling between excitons and Mie modes results in Fano lineshapes in the spectral domain [1]. Here, we use a new broadband, interferometric sSNOM technique [2] to probe the time dynamics of the local optical near-fields of such particles. We measure amplitude and phase of the scattered light field in a broad spectral range and with 10 nm spatial resolution. Direct Fourier transformation gives the time dynamics of the local electric field, recorded with sub-cycle resolution. We uncover biexponential near-field decays with a characteristic destructive interference dip after a few fs. In the spectral domain, this corresponds to a Fano resonance with an unual 2π phase jump. We show that this signature arises from the intereference between spectrally broad dipole and narrow quadrupole resonances of the particles. Our results give new insight into the optical properties of high-index, active semiconductor nanoparticles with intriguing applicatoins for nanoscale all-opticals switching and lasing. [1] Tiguntseva, E. Y., et al. Nano Lett. 2018, 18 (2), 1185-1190. [2] Zhan, J., et al. Advanced Photonics 2020, 2 (04).

Q 71.2 Fri 14:45 HS 3219

Dynamics of exciton-polaritons in optically driven ZnO nano-particles — Andreas Lubatsch[1] and •Regine Frank[2,3] — [1]Physikalisches Institut, Rheinische Friedrich Wilhelms Universitaet Bonn — [2]College of Biomedical Sciences, Larkin University, Miami, Florida, USA — [3]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain

We implement externally excited ZnO Mie resonators in a framework of a generalized Hubbard Hamiltonian to investigate the lifetimes of excitons and exciton-polaritons out of thermodynamical equilibrium. Our results are derived by a Floquet-Keldysh-Green's functions formalism with Dynamical Mean Field Theory (DMFT) and a second order iterative per-turbation theory solver (IPT). We find polaritons that result from a Fano resonance in the sense of coupling of the continuum of the LDOS to the quantised ZnO resonator mode with lifetimes between 0.6 ps and 1.45 ps. Our results are compared to recent experiments of ZnO polariton lasers and to ZnO random lasers.

[1] A. Lubatsch, R. Frank, Appl. Sci. 2020, 10, 1836 [2] A. Lubatsch,R. Frank, Symmetry 2019, 11, 1246 [3] T.-C. Lu, et. al. Opt. Express 2012, 20, 5530

Q 71.3 Fri 15:00 HS 3219

Magnetoplasmonic routing components: isolator, switch, circulator — •Sevag Abadian, Michail Symeonidis, Marian Bogdan Sirbu, and Tolga Tekin — Fraunhofer IZM, Gustav-Meyer-Allee 25/Gebäude 17, 13355 Berlin

The surge in data traffic driven by mobile apps, high-definition content, IoT, and AR is intensifying the demand for data centers to rapidly process and store massive amounts of information. PICs hold promise for data centers by potentially reducing power consumption and space requirements while optimizing data traffic management. Advancement of routing components which play a pivotal role in enabling efficient and seamless data flow across diverse applications, is a must. To achieve these functionalities, a medium that breaks spatial and time symmetry is necessary. Among the different mechanisms used, magneto-plasmonics has emerged as an efficient tool to be exploited. Plasmonic slot waveguides can host coupled SPP modes which under external magnetization, loose their symmetric and anti-symmetric modal profiles and become asymmetric and anti-asymmetric. For isolators, this opens up the way for switching the light path in the forward and backward directions between the parallel plasmonic interfaces, allowing the creation of high amplitude difference when the backward travelling wave is completely absorbed or radiated by cavities or gratings. For switches or circulators, this opens up the way for switching the light path to one of the two or three arms. Magneto-plasmonics has emerged as a satisfactory solutions for integratable routing components with high efficiency and small footprint.

Q 71.4 Fri 15:15 HS 3219

Ultrafast near-field scanning optical oscilloscopy — •Juanmei Duan, Tom Jehle, Sam Nochowitz, and Christoph Lienau — Universität Oldenburg, D-26129, Germany

Metallic, dielectric and hybrid nanoparticles offer exciting opportunities to localize, manipulate and switch light on the nanoscale. A direct measurement of the local electric field at the surface of the nanostructures is challenging however, since these fields are often localized on exceedingly short length and time scales. While experiments such as attosecond photoelectron emission microscopy or phase-resolved photon-induced near-field electron microscopy have been proposed, direct time-resolved measurements are still lacking. Here, we describe and demonstrate a new experimental technique, ultrafast near-field oscilloscopy, to probe coherent optical near-fields in the time with nanometer spatial resolution. For this, amplitude and phase of the local near-field scattered by a sharp metal taper are recorded in a broad spectral range and on a time scale that is faster than the tip modulation period. This allows us to record spectra as a function of tip-sample distance, the key to probe tip-sample coupling experimentally. Direct Fourier transform of the scattering spectra gives the local near-field dyanamics with sub-cycle temporal and nanometer spatial resolution. We demonstrate the versatility of this new approach by probing near-fields of dielectric and semiconducting nanoparticles, as well as different localized and propagating plasmon mode of metal nanostructures.

Q 71.5 Fri 15:30 HS 3219

Ultrabright single photon sources from single molecules — •Subhabrata Ghosh, Yijun Wang, Maximilian Luka, and Ilja Gerhardt — light & matter Group, Institute for Solid State Physics, Leibniz University Hannover, Appelstrasse 2, D-30167 Hannover, Germany

A single photon source emits a stream of individual photons at most one at a time and one after the another. Single organic dye molecules are considered as versatile single photon sources due to their very narrow line widths and negligible spectral diffusion. One of the major issues with single photon sources is the engineering towards a maximal photon flux and how to detect these photons then efficiently. The brightness and purity of single photon sources are measured by saturation scans and intensity auto-correlation functions. The high brightness of the single photon sources with very narrow spectral width at 1K will be presented. These sources can play an important role in quantum communications and technology.

Q 71.6 Fri 15:45 HS 3219

On-chip interference of scattering from two individual molecules — •Alexey Shkarin[1], Dominik Rattenbacher[1], Jan Renger[1], Tobias Utikal[1], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich Alexander University Erlangen-Nuremberg, D-91058 Erlangen, Germany

Scaling up quantum optical networks entail interconnecting ever larger number of remote quantum emitters through optical means. The most technologically-compatible way of doing this involves coupling multiple emitters to photonic chip structures prepared according to the experimental requirements. Such efforts are frequently stymied by low coupling efficiency of emitters to photonic structures, which is often overcome through resonant enhancement. In our work, we employ onchip disk resonators evanescently coupled to multiple dibenzoterrylene molecules serving as optically active quantum two-level system. To preserve the quality factor of the resonators, we use polyethylene (PE) as a host material for molecules. Somewhat surprisingly, despite disordered nature of PE we find that a large fraction of molecules preserve their excellent optical properties, including lifetime-limited linewidths. Thanks to the high resonator finesse, we observe Purcell enhancement of almost an order of magnitude in the emission and strong molecule-induced extinction of the resonator mode. Finally, we simultaneously couple two molecules at the same frequency and observe significant suppression of backwards scattering compared to a single emitter.

Q 71.7 Fri 16:00 HS 3219

Fourier-limited Single Molecules on a Surface — •Masoud Mirzaei[1,2], Alexey Shkarin[1], Johannes Zirkelbach[1], Ashley Jiwon Shin[1], Jan Renger[1], Tobias Utikal[1], Stephan Götzinger[1,2,3], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander University Erlangen-Nürnberg, 91052 Erlangen, Germany

We investigate the spectroscopic properties of individual dibenzoterrylene (DBT) molecules on pristine anthracene crystal surfaces at sub-Kelvin temperatures. By quantifying temperature-induced dephasing effects on the molecular transitions, we show that dephasing becomes negligible below 2K, leading to Fourier-limited zero-phonon lines in DBT. We report on the spectral stability of single molecule transitions as a function of laser power. Furthermore, polarization sensitive measurements allow us to determine the transition dipole orientation, which in turn provides direct information about the preferred orientation of DBT molecules on anthracene crystal surfaces, in agreement with theoretical predictions. Our work marks the first instance of a lifetime-limited emission for molecules placed on naked surfaces, opening the door to investigations in the deep optical near-field regime, where atomic-resolution microscopy can be combined with high-resolution molecular spectroscopy.

Q 71.8 Fri 16:15 HS 3219

High-resolution cryogenic spectroscopy of single organic molecules in printed nanocrystals — •Mohammad Musavinezhad[1,3], Jan Renger[1], Johannes Zirkelbach[1], Tobias Utikal[1], Claudio U. Hail[2], Dimos Poulikakos[2], Stephan Götzinger[1,3], and Vahid Sandoghdar[1,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]ETH, Zürich, Switzerland — [3]FAU Erlangen-Nuremberg, Erlangen, Germany.

Organic dye molecules have shown promising functionalities in quantum photonic devices, but deterministic control of the molecules' position and density remains a challenge. Here, we extend our previous efforts on printing organic nanocrystals (NCs) [1] to the new system of dibenzoterrylene (DBT) in anthracene (Ac). We examined the zero-phonon transitions of individual DBT molecules in printed Ac NCs at 2 K. By using high-resolution fluorescence excitation spectroscopy, we confirm that single-molecule transitions in printed NCs are nearly as narrow as their lifetime-limited counterparts in bulk Ac. Moreover, we show that resonance instabilities are typically less than one linewidth. We characterize the orientation and lateral coordinates of individual molecules in a large number of NCs to assess the degree of crystallinity and the lateral dimensions of the printed structures [2]. The combination of the emitters' subwavelength placement precision enabled by our nanoprinting method and their spectral quality makes them attractive candidates for integration into quantum optical circuits.

[1] Hail, C. U. et al., Nat Commun 10, 1880 (2019).
[2] Musavinezhad, M. et al., submitted.