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

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Overview of Invited Talks and Sessions

(Lecture rooms K 0.016, K 0.023, K 1.013, K 1.019, K 1.020, K 1.022, K 2.013, and K 2.020;
Poster Redoutensaal, Orangerie, Zelt Ost, and Zelt West)

Invited talks of the joint symposium SYPS

See SYPS for the full program of the symposium.

SYPS 1.1	Mon	14:00–14:30	RW HS	**Floquet engineering of interacting quantum gases in optical lattices** — •André Eckardt
SYPS 1.2	Mon	14:30–15:00	RW HS	**Experiments on driven quantum gas and surprises** — •Cheng Chin
SYPS 1.3	Mon	15:00–15:30	RW HS	**Exploring 4D Quantum Hall Physics with a 2D Topological Pumps** — •Oded Zilberberg, Michael Lohse, Christian Schweizer, Immanuel Bloch, Hannah Price, Yaacov Kraus, Sheng Huang, Mohan Wang, Kevin Chen, Jonathan Guglielmon, Mikael Rechtsman
SYPS 1.4	Mon	15:30–16:00	RW HS	**Floquet Discrete Time Crystals in a Trapped-Ion Quantum Simulator** — •Guido Pagano, Jiehang Zhang, Paul Hess, Antonis Kyprianidis, Patrick Becker, Jacob Smith, Aaron Lee, Norman Yao, Tobias Grass, Alessio Celi, Maciej Lewenstein, Christopher Monroe

Invited talks of the joint symposium SYAD

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	10:30–11:00	RW HS	**Integrated photonic quantum walks in complex lattice structures** — •Markus Graefe
SYAD 1.2	Tue	11:00–11:30	RW HS	**Testing the Quantumness of Atom Trajectories** — •Carsten Robens
SYAD 1.3	Tue	11:30–12:00	RW HS	**Engineering and probing topological bands with ultracold atoms** — •Nick Fläschner
SYAD 1.4	Tue	12:00–12:30	RW HS	**Statistical signatures of many-particle interference** — •Mattia Walschaers

Invited talks of the joint symposium SYET

See SYET for the full program of the symposium.

SYET 1.1	Thu	11:00–11:30	RW HS	**The quantum design of photosynthesis** — •rienk van Grondelle
SYET 1.2	Thu	11:30–12:00	RW HS	**On systems with and without excess energy in environment: ICD and other interatomic mechanisms** — •Lorenz Cederbaum
SYET 1.3	Thu	12:00–12:30	RW HS	**Molecular QED of Resonance Energy Transfer: Pair and Many-Body Theory** — •Akbar Salam
SYET 1.4	Thu	12:30–13:00	RW HS	**The Experimental Investigation of Interatomic/Intermolecular Coulombic Decay** — •Uwe Hergenhahn

Invited talks of the joint symposium SYQC

See SYQC for the full program of the symposium.

SYQC 1.1	Thu	14:00–14:30	RW HS	**The resource theory of quantum coherence** — •Martin B Plenio

SYQC 1.2	Thu	14:30–15:00	RW HS	**Interferometric visibility and coherence** — •Andreas Winter
SYQC 1.3	Thu	15:00–15:30	RW HS	**Quantum coherence and interference patterns** — •Florian Mintert
SYQC 1.4	Thu	15:30–16:00	RW HS	**Experiments on directly measuring quantum coherence and using it for quantum sensing** — •Chuan-Feng Li

Invited talks of the joint symposium SYMM

See SYMM for the full program of the symposium.

SYMM 1.1	Fri	13:30–14:00	RW HS	**Some experimental contributions to the study of thermodynamics in quantum systems.** — •Ian Walmsley
SYMM 1.2	Fri	14:00–14:30	RW HS	**Levitated Nanoparticle Micromachines** — •Nikolai Kiesel
SYMM 1.3	Fri	14:30–15:00	RW HS	**Autonomous quantum machines and timekeeping** — •Marcus Huber
SYMM 1.4	Fri	15:00–15:30	RW HS	**An autonomous thermal machine for amplification of coherence** — •Juan MR Parrondo, Gonzalo Manzano, Ralph Silva

Sessions

Q 1.1–1.6	Mon	10:30–12:00	K 0.011	**Cold atoms I - Rydbergs (joint session A/Q)**
Q 2.1–2.7	Mon	10:30–12:30	K 0.016	**Quantum Optics I**
Q 3.1–3.9	Mon	10:30–12:45	K 0.023	**Ultrashort Laser Pulses**
Q 4.1–4.8	Mon	10:30–12:30	K 1.013	**Matter Wave Optics I**
Q 5.1–5.5	Mon	10:30–12:00	K 1.016	**Precision Spectrosocopy I - trapped ions (joint session A/Q)**
Q 6.1–6.7	Mon	10:30–12:30	K 1.019	**Quantum Information (Concepts and Methods) I**
Q 7.1–7.7	Mon	10:30–12:30	K 1.020	**Quantum Information (Quantum Computing)**
Q 8.1–8.6	Mon	10:30–12:15	K 2.013	**Ultracold Plasmas and Rydberg Systems I (joint session Q/A)**
Q 9.1–9.6	Mon	10:30–12:00	K 2.019	**Cold atoms II - interactions (joint session A/Q)**
Q 10.1–10.8	Mon	10:30–12:30	K 2.020	**Quantum Gases (Bosons) I**
Q 11.1–11.6	Mon	14:00–15:30	K 0.011	**Cold atoms III - optical lattices (joint session A/Q)**
Q 12.1–12.8	Mon	14:00–16:00	K 0.016	**Quantum Optics II**
Q 13.1–13.7	Mon	14:00–15:45	K 0.023	**Laser Development and Applications (joint session Q/A)**
Q 14.1–14.5	Mon	14:00–15:45	K 1.016	**Precision Spectrosocopy II - trapped ions (joint session A/Q)**
Q 15.1–15.7	Mon	14:00–16:00	K 1.019	**Quantum Information (Concepts and Methods) II**
Q 16.1–16.7	Mon	14:00–15:45	K 1.020	**Quantum Information and Simulation**
Q 17.1–17.9	Mon	14:00–16:15	K 2.016	**Bose-Einstein Condensation (joint session A/Q)**
Q 18.1–18.8	Mon	14:00–16:00	K 2.020	**Quantum Gases (Bosons) II**
Q 19.1–19.5	Mon	16:15–17:30	K 0.011	**Cold atoms IV - topological systems (joint session A/Q)**
Q 20.1–20.6	Mon	16:15–17:45	K 0.016	**Quantum Optics III**
Q 21.1–21.6	Mon	16:15–17:45	K 0.023	**Optomechanics I**
Q 22.1–22.6	Mon	16:15–17:45	K 1.013	**Matter Wave Optics II**
Q 23.1–23.5	Mon	16:15–17:45	K 1.016	**Precision Spectrosocopy III - trapped ions (joint session A/Q)**
Q 24.1–24.6	Mon	16:15–17:45	K 1.020	**Quantum Information (Solid State Systems)**
Q 25.1–25.7	Mon	16:15–18:00	K 1.022	**Quantum Gases (Fermions) I**
Q 26.1–26.5	Mon	16:15–17:30	K 2.013	**Ultracold Plasmas and Rydberg Systems II (joint session Q/A)**
Q 27.1–27.6	Mon	16:15–17:45	K 2.020	**Quantum Gases (Bosons) III**
Q 28.1–28.6	Tue	14:00–15:30	K 0.011	**Cold atoms V - optical lattices (joint session A/Q)**
Q 29.1–29.8	Tue	14:00–16:00	K 0.016	**Quantum Optics and Photonics I**
Q 30.1–30.6	Tue	14:00–15:30	K 0.023	**Optomechanics II**
Q 31.1–31.7	Tue	14:00–15:45	K 1.013	**Quantum Effects (QED)**
Q 32.1–32.6	Tue	14:00–15:45	K 1.016	**Precision Spectroscopy IV - highly charged ions (joint session A/Q)**
Q 33.1–33.7	Tue	14:00–16:00	K 1.019	**Quantum Information (Concepts and Methods) III**
Q 34.1–34.7	Tue	14:00–15:45	K 1.020	**Quantum Information (Quantum Communication)**
Q 35.1–35.9	Tue	14:00–16:15	K 1.022	**Quantum Gases (Fermions) II**
Q 36.1–36.6	Tue	14:00–15:30	K 2.013	**Ultracold Molecules**

Q 37.1–37.8	Tue	14:00–16:00	K 2.020	**Quantum Gases (Bosons) IV**
Q 38.1–38.20	Tue	16:15–18:15	Orangerie	**Poster: Quantum Optics and Photonics I**
Q 39.1–39.23	Tue	16:15–18:15	Zelt Ost	**Poster: Quantum Optics and Photonics II**
Q 40.1–40.24	Tue	16:15–18:15	Zelt West	**Poster: Quantum Optics and Photonics III**
Q 41.1–41.7	Wed	14:00–15:45	K 0.011	**Ultracold Plasmas and Rydberg systems III (joint session A/Q)**
Q 42.1–42.7	Wed	14:00–16:00	K 0.016	**Quantum Optics and Photonics II**
Q 43.1–43.8	Wed	14:00–16:15	K 0.023	**Nano-Optics (Single Quantum Emitters)**
Q 44.1–44.7	Wed	14:00–16:00	K 1.013	**Quantum Effects (Cavity QED)**
Q 45.1–45.7	Wed	14:00–15:45	K 1.016	**Precision Spectroscopy V - highly charged ions (joint session A/Q)**
Q 46.1–46.9	Wed	14:00–16:15	K 1.019	**Quantum Information (Concepts and Methods) IV**
Q 47.1–47.7	Wed	14:00–16:00	K 1.020	**Quantum Information (Quantum Repeater)**
Q 48.1–48.9	Wed	14:00–16:15	K 1.022	**Quantum Gases (Fermions) III**
Q 49.1–49.5	Wed	14:00–15:30	K 2.013	**Precision Measurements and Metrology (Atom Interferometry) (joint session Q/A)**
Q 50.1–50.8	Wed	14:00–16:00	K 2.020	**Quantum Gases (Bosons) V**
Q 51.1–51.69	Wed	16:15–18:15	Redoutensaal	**Poster: Quantum Optics and Photonics IV**
Q 52.1–52.7	Thu	10:30–12:15	K 0.011	**Cold atoms VI - traps (joint session A/Q)**
Q 53.1–53.8	Thu	10:30–12:30	K 0.016	**Quantum Optics and Photonics III**
Q 54.1–54.9	Thu	10:30–12:45	K 0.023	**Nano-Optics (Single Quantum Emitters and Plasmonics)**
Q 55.1–55.7	Thu	10:30–12:30	K 1.013	**Quantum Effects**
Q 56.1–56.8	Thu	10:30–12:30	K 1.019	**Quantum Information (Coherence and Entanglement)**
Q 57.1–57.7	Thu	10:30–12:15	K 1.022	**Ultracold Atoms I (joint session Q/A)**
Q 58.1–58.6	Thu	10:30–12:00	K 2.013	**Precision Measurements and Metrology (Gravity and Miscellaneous) (joint session Q/A)**
Q 59.1–59.9	Thu	10:30–12:45	K 2.020	**Quantum Gases (Bosons) VI**
Q 60	Thu	12:45–13:30	K 2.013	**Annual General Meeting of the Quantum Optics and Photonics Division**
Q 61.1–61.7	Thu	14:00–16:00	K 1.016	**Precision Spectroscopy VI - neutrals and ions (joint session A/Q)**
Q 62.1–62.101	Thu	16:15–18:15	Redoutensaal	**Poster: Quantum Optics and Photonics V**
Q 63.1–63.5	Fri	10:30–11:50	K 0.011	**Cold atoms VII - micromachines (joint session A/Q)**
Q 64.1–64.8	Fri	10:30–12:30	K 0.016	**Quantum Optics and Photonics IV**
Q 65.1–65.7	Fri	10:30–12:15	K 0.023	**Nano-Optics and Biophotonics**
Q 66.1–66.8	Fri	10:30–12:30	K 1.013	**Quantum Effects (Entanglement and Decoherence)**
Q 67.1–67.8	Fri	10:30–12:30	K 1.016	**Precision Spectrosocopy VII (nuclear systems) (joint session A/Q)**
Q 68.1–68.8	Fri	10:30–12:30	K 1.019	**Quantum Information (Concepts and Methods) V**
Q 69.1–69.4	Fri	10:30–11:30	K 1.020	**Post-Deadline Session**
Q 70.1–70.8	Fri	10:30–12:30	K 1.022	**Ultracold Atoms II (joint session Q/A)**
Q 71.1–71.7	Fri	10:30–12:15	K 2.013	**Precision Measurements and Metrology (Optical Clocks) (joint session Q/A)**

Annual General Meeting of the Quantum Optics and Photonics Division

Thursday 12:45–13:30 K 2.013

Q 1: Cold atoms I - Rydbergs (joint session A/Q)

Time: Monday 10:30–12:00 Location: K 0.011

Q 1.1 Mon 10:30 K 0.011

Probing many-body dynamics on a 51-atom quantum simulator — •Ahmed Omran[1], Hannes Bernien[1], Alexander Keesling[1], Harry Levine[1], Sylvain Schwartz[1,2], Hannes Pichler[3,1], Soonwon Choi[1], Markus Greiner[1], Vladan Vuletic[2], and Mikhail D. Lukin[1] — [1]Department of Physics, Harvard University, Cambridge, MA 02138, USA — [2]Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA — [3]Institute for Theoretical Atomic Molecular and Optical Physics, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA

The realization and control of large-scale quantum systems is an exciting frontier of modern physical science. Using a novel cold atom platform, we trap single neutral atoms in an array of optical tweezers, and use real-time feedback to prepare defect-free chains of tens of atoms in one dimension with a high fidelity and repetition rate [1]. Excitation of the atoms to Rydberg states enables strong and tunable van der Waals interactions over long distances, which allows for engineering an Ising-type Hamiltonian with non-trivial spatial correlations between Rydberg atoms.

The flexibility and controllability of our platform enables us to perform powerful simulations of quantum many-body systems in and out of equilibrium and shed light on the quantum dynamics around different phase transitions and following sudden quantum quenches [2].

[1] M. Endres et al., Science 354, 1024-1027 (2016)

[2] H. Bernien et al., Nature 551, 579-584 (2017)

Q 1.2 Mon 10:45 K 0.011

Spin-Interaction Effects for Ultralong-range Rydberg Molecules in a Magnetic Field — •Frederic Hummel[1], Christian Fey[1], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We investigate the fine and spin structure of ultralong-range Rydberg molecules exposed to a homogeneous magnetic field. Each molecule consists of a ^{87}Rb Rydberg atom whose outer electron interacts via spin-dependent s- and p-wave scattering with a polarizable ^{87}Rb ground state atom. Our model includes also the hyperfine structure of the ground state atom as well as spin-orbit couplings of the Rydberg and ground state atom. We focus on d-Rydberg states and principal quantum numbers n in the vicinity of 40. The electronic structure and vibrational states are determined in the framework of the Born-Oppenheimer approximation for varying field strengths ranging from a few up to hundred Gauß. The results show that the interplay between the scattering interactions and the spin couplings gives rise to a large variety of molecular states in different spin configurations as well as in different spatial arrangements that can be tuned by the magnetic field. We quantify the impact of spin couplings by comparing the extended theory to a spin-independent model.

Q 1.3 Mon 11:00 K 0.011

Coupling Rydberg atoms and superconducting resonators — •Helge Hattermann, Li Yuan Ley, Conny Glaser, Daniel Bothner, Benedikt Ferdinand, Lörinc Sárkány, Reinhold Kleiner, Dieter Koelle, and József Fortágh — CQ Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

We report on the the coupling between ultracold ^{87}Rb Rydberg atoms and a driven coplanar waveguide resonator on a superconducting atom chip. The superconducting cavity at 20.5 GHz is near-resonant to the transition frequency between Rydberg states. Driven transitions are detected by state selective field ionization of the Rydberg states.

Close to the chip, Rydberg states are strongly affected by the electric field of adsorbates on the chip, leading to spatially inhomogeneous energy shifts.

Coupling Rydberg atoms to coplanar superconducting resonators has been proposed for efficient state transfer between solid state systems and ultracold atoms, the generation of an atomic quantum memory and the implementation of novel quantum gates [1].

[1] L. Sárkány et al., Phys. Rev. A 92, 030303 (2015).

Q 1.4 Mon 11:15 K 0.011

Non-equilibrium criticality in driven Rydberg gases — •Graham Lochead[1,2], Stephan Helmrich[1], Alda Arias[1,2], Henrik Hirzler[1], Tobias Wintermantel[1,2], Michael Buchhold[3], Sebastian Diehl[4], and Shannon Whitlock[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Institut de Physique et de Chimie des Matériaux de Strasbourg (IPCMS), University of Strasbourg, France 67200 — [3]California Institute of Technology, 1200 E California Boulevard, CA 91125, Pasadena, U.S. — [4]Institut für Theoretische Physik, Universität zu Köln, D-50937 Cologne

We study the dynamics of well controlled systems of ultracold atoms excited to long-range interacting Rydberg states by an off-resonant laser field. Starting from an initial seed excitation, there is a characteristic distance at which the interaction energy precisely matches the laser detuning, thus facilitating further excitations. This interplay between coherent driving, dissipation and long-range interactions can lead to rich many body dynamics, including self similar evolution and scale invariant behavior. We present experiments on the temporal evolution of the system as a function of the amplitude of the driving field and investigate possible links to paradigmatic non-equilibrium universality classes such as directed percolation and self-organized criticality. This opens a new route to explore non-equilibrium critical phenomena in three-dimensions, and in settings where quantum and classical fluctuations can compete on an equal footing.

Q 1.5 Mon 11:30 K 0.011

Accurate Rydberg quantum simulations of spin-1/2 models — •Sebastian Weber[1], Sylvain de Léséleuc[2], Vincent Lienhard[2], Daniel Barredo[2], Thierry Lahaye[2], Antoine Browaeys[2], and Hans Peter Büchler[1] — [1]Institute for Theoretical Physics III, University of Stuttgart, Germany — [2]Laboratoire Charles Fabry, Institut d'Optique, CNRS, Université Paris-Saclay, France

Using non-perturbative calculations of the interaction potentials between two Rydberg atoms taking into account both electric and magnetic fields, we can simulate a broad range of two-atom Rydberg systems. Benchmarks against varied experimental data show an excellent agreement between the simulations and experiments. We apply our simulation procedure to investigate under which experimental conditions spin-1/2 models can be accurately simulated using Rydberg atoms. More specifically, we determine experimental parameters for which a system of atoms that are laser driven to $nD_{3/2}$ Rydberg states and interacting via the van der Waals interaction can be mapped accurately to an Ising-like spin-1/2 model, despite the large number of Rydberg levels involved. Our investigations show the importance of a careful selection of experimental parameters in order not to break the Rydberg blockade mechanism which underlies the mapping. By selecting appropriate parameters, even in a large system of 49 Rydberg atoms, an excellent agreement is achieved between the measured time evolution and the numerically calculated dynamics of the Ising-like spin-1/2 model. This result opens exciting prospects for the realization of high-fidelity quantum simulators of spin Hamiltonians.

Q 1.6 Mon 11:45 K 0.011

The impact of ionization laser polarization on spatio-temporal distribution of photoelectrons from Cs atoms in a MOT — •Olena Fedchenko[1], Sergey Chernov[1], Melissa Vielle-Grosjean[2], Gerd Schönhense[1], and Daniel Comparat[2] — [1]Institut für Physik, JGU Mainz, Germany — [2]University Paris-Sud, Orsay, France

We present results of investigation of the properties of a monochromatic photoelectron source based on near threshold photoionization of cold Cs atoms in MOT by time-of-flight momentum microscopy [1]. A 3D-stack of experimental results was obtained under absence of magnetic field. For this purpose a scheme with switched trapping B-field was used in the DC-MOT: 5 ms to load the MOT and 4 ms for excitation (@1470 nm, 1 ms exposition). Measurements were done for different linear polarizations of the ionizing Ti-sapphire fs-laser. Study of near-threshold photoionization with different gradients of the extracting electric field showed that the difference between signals with s- and p-polarization of the ionization light was due to real dichroism and partly due to contribution of field ionization of Rydberg states.

Variation of the bandwidth of the Ti-sapphire laser revealed that in case of broad bandwidth several photoionization paths took place simultaneously. Namely, excitation of Rydberg atoms had place in the combination with subsequent field ionization and photoionization from higher states. To study the energy and time spread of photoelectrons, an accelerator with homogeneous pulsed electric field is proposed.

[1] O. Fedchenko et al., Appl. Phys. Lett, 111, 021104 (2017).

Q 2: Quantum Optics I

Time: Monday 10:30–12:30 Location: K 0.016

Group Report Q 2.1 Mon 10:30 K 0.016

Ultrafast quantum optics with temporal modes — •Vahid Ansari, Markus Allgaier, John M Donohue, Matteo Santandrea, Laura Padberg, Christof Eigner, Mahnaz Doostdar, Gesche Vigh, Linda Sansoni, Georg Harder, Benjamin Brecht, and Christine Silberhorn — Integrierte Quantenoptik, Universität Paderborn, Warburger Str. 100, D-33098 Paderborn

Temporal modes of photonic quantum states provide a rich framework for quantum information science. They constitute a high-dimensional Hilbert space and are compatible with the existing single-mode fibre communication networks.

In this report, we show how to create ultrashort single photons in arbitrary temporal shapes, based on ultrafast waveguided parametric down-conversion (PDC) at telecom wavelengths. By tailoring the PDC process, we can control the spectral-temporal structure of the generated states to create separable or entangled photon pairs with a well-defined number of temporal modes.

Then we use a quantum pulse gate (QPG), based on a dispersion-engineered frequency conversion device, to manipulate and detect the underlying temporal structure of multimode PDC states within a high-dimensional space. Using the QPG, we present our recent experiments on temporal-mode tomography, purification of multimode PDC states, efficient bandwidth compression of single photons, and remote state preparation of arbitrary temporal modes.

Q 2.2 Mon 11:00 K 0.016

A Source of correlated photons for femtosecond quantum spectroscopy — •Fabiano Lever, Axel Heuer, Jan Metje, and Markus Guehr — Institut für Physik und Astronomie 0.033, Haus 28, Karl-Liebknecht-Straße 24/25 14476 Potsdam-Golm

In this work, we present a source of down converted photons for future use in nonlinear quantum spectroscopy, in our case on a halogen gas sample. The broadband signal and idler photons which are generated from a narrowband pump pulse are chosen to be resonant with electronic transitions in the sample. The idler pulse creates a nuclear wavepacket whose state is then read by the signal pulse. Although the duration of the two pulses is long, as determined by the narrowband pump, time resolution is obtained due to quantum correlations.

The pump light for the down conversion is obtained in a two step process, a femtosecond Yb:KGW laser is first shifted via transient stimulated Raman scattering and subsequently doubled in an non critically phase matched LBO. A chirped PPLN crystal is then used to obtain a broadband downconversion of the pump into correlated signal and idler beams.

Q 2.3 Mon 11:15 K 0.016

Generation of Multimode Photonic States for Quantum Metrology — •Vanessa Paulisch, Martí Perarnau Llobet, Alejandro González-Tudela, and J. Ignacio Cirac — Max-Planck-Institute of Quantum Optics, Garching, Germany

The high fidelity generation of photonic states is crucial for quantum communication and quantum metrology with photons. We study the conditions under which a chain of emitters coupled to a one dimensional waveguide emits a photonic state. We have shown that arbitrary photonic states of a single mode (Fock states or superpositions thereof) can be generated when the number of emitters is much larger than the number of excitations in the emitters, i.e., the number of photons to be generated. On the other hand, when the emitters are fully excited, they emit a intricate multimode photonic state. It was unclear whether these states are as useful as the more standard single mode states. We show that, indeed, also these multimode photonic states are useful for quantum metrology on the example of a phase measurement. And quite remarkably, they still easily beat the standard quantum limit of phase estimation.

Q 2.4 Mon 11:30 K 0.016

All-optically generation of tensor network states in one and higher dimensions — •Melanie Engelkemeier[1], Ish Dhand[2], Linda Sansoni[1], Sonja Barkhofen[1], Christine Silberhorn[1], and Martin Plenio[2] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]Universität Ulm, Institut für Theoretische Physik, Helmholtzstraße 16, 89081 Ulm

In order to realize one- and higher-dimensional tensor network states of light, we propose to generate entangled multi-mode photonic states encoded in temporal modes of light with an all-optical scheme. Within this scheme, we are able to generate two different classes of entangled tensor-network states (W and GHZ states), which are suitable for quantum communication and quantum computation applications. Furthermore, we present a variational algorithm to simulate the ground-state physics of many-body systems and show that the existing optical devices are capable of implementing the spin-1/2 Heisenberg model. Finally, we demonstrate that the scheme is robust against experimental imperfections, such as realistic losses and modemismatch.[1]

[1] arXiv:1710.06103 [quant-ph]

Q 2.5 Mon 11:45 K 0.016

Broadening of spatial Schmidt modes for high-gain parametric down-conversion — •Gaetano Frascella[1], Polina Sharapova[2], Angela M. Pérez[1], and Maria V. Chekhova[1,3] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]University of Padeborn, 33098 Padeborn, Germany — [3]Physics Department, Moscow State University, 119991 Moscow, Russia

High-gain parametric down-conversion (PDC) is a well-known process for the production of bright squeezed vacuum (BSV) state of light, whose nonclassical features, like macroscopic photon-number entanglement, can be employed in quantum information and imaging.

The Schmidt modal decomposition is a powerful tool for the characterization of PDC's multimode structure because it offers a set of paired eigenmodes that show no correlations with other modes.

The measurement of single-shot two-dimensional far-field intensity distributions and the calculation of the covariance distribution enables the determination of the shapes and the weights of the spatial/angular Schmidt modes.

In this work, we experimentally reconstruct the spatial/angular Schmidt modes for BSV generated through high-gain PDC from a single nonlinear crystal and we show that both the angular spectrum and the Schmidt modes broaden slightly as the parametric gain increases.

This result suggests that a correction should be made to the model of gain-independent Schmidt modes.

Q 2.6 Mon 12:00 K 0.016

Photonenkorrelationsfunktion $g^{(2)}$ gemessen im Licht eines Ionenpaars - bunching oder anti-bunching? — •Sebastian Wolf[1], Stefan Richter[2], Joachim von Zanthier[2] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen

Die Messung der Photonenstatistik einer klassischen thermischen Lichtquelle zeigt bunching, also $g^{(2)}(0) > 1$, während eine Laserlichtquelle $g^{(2)}(0) = 1$ zeigt. Wieder andere Photonenstatistik – antibunching mit $g^{(2)}(0) < 1$ – beobachtet man für ein einzelnes Atom oder Ion. Wir berichten über den Nachweis ortsabhängiger Photonenstatistik im gestreuten Licht eines Zwei-Ionen-Kristalls in einer Paulfalle. Dieser wird mit einem Laser kontinuierlich angeregt und das emittierte Fluoreszenzlicht mit einem Objektiv gesammelt. Ein Aperturschlitz lässt dabei nur Licht aus einem schmalen Raumwinkelbereich in den Messaufbau für $g^{(2)}(t)$. Wir beobachten Werte von $g^{(2)}(0)$, die je nach Position des Schlitzes zwischen einem Maximum von 1.53(11) und einem Minimum von 0.58(6) variieren. Alternativ können wir durch Änderung des Ionenabstandes von bunching zu anti-bunching wechseln. Diese einzigartigen Eigenschaften der Photonenstatistik resultieren aus der Projektion des zwei-Ionen-Systems in einen Bell-Zustand, dessen Phase von der Richtung des einfallenden Lasers und der Beobachtungsrichtung abhängt [1].

[1] C. Skornia et al., Phys. Rev. A **64**, 063801 (2001).

Q 2.7 Mon 12:15 K 0.016

Attosecond Electron Pulse Trains and Quantum State Reconstruction in Ultrafast Transmission Electron Microscopy — Katharina E. Priebe[1], Christopher Rathje[1,2], •Thomas Rittmann[1], Sergey V. Yalunin[1], Thorsten Hohage[3], Armin Feist[1], Sascha Schäfer[1,2], and Claus Ropers[1] — [1]4th Physical Institute, University of Göttingen, Germany — [2]Institut für Physik, University of Oldenburg, Germany — [3]Institut für Numerische und Angewandte Mathematik, University of Göttingen, Germany

In an ultrafast transmission electron microscope (UTEM), inelastic scattering between the free-electron beam and strong optical near-fields [1] allows for coherent manipulations of the electron quantum state [2]. Specifically, a light field imprints a phase modulation on the electron wave function, which is translated into an attosecond-structured electron density modulation by subsequent dispersive propagation [3].

Here, we employ multiple phase-locked field interactions to reconstruct the temporal structure of the electron density with our newly developed quantum state tomography technique 'SQUIRRELS' [4]. We experimentally demonstrate the compression of electron pulses into a train of attosecond bursts, which will promote new forms of ultrafast electron microscopy with attosecond resolution.

[1] B. Barwick *et al.*, Nature **462**, 902-906 (2009)
[2] K. Echternkamp *et al.*, Nature Physics **12**, 1000-1004 (2016)
[3] A. Feist *et al.*, Nature **521**, 200-203 (2015)
[4] K. Priebe *et al.*, Nature Photonics **11**, 793-797 (2017)

Q 3: Ultrashort Laser Pulses

Time: Monday 10:30–12:45 Location: K 0.023

Q 3.1 Mon 10:30 K 0.023

Noncollinear third harmonic generation in MgO — •Dennis Mayer, Axel Heuer, and Markus Gühr — Institut für Physik und Astronomie, Universität Potsdam

In a recent study You et al. observed that harmonic generation in MgO is sensitive to the crystal structure and that the polarization dependent efficiency exhibits additional features in the strong field regime [1]. In contribution to this study we report the observation of intensity- and polarization-dependent far field patterns in the perturbative third harmonic generation in MgO. Using 400fs pulses from an Yb-based laser we observed a transition from collinear to different non-collinear emissions depending on the pump-pulse polarization at intensities of 10^{11} W/cm^2. The emission is locked to the Mg-O direction inside the crystal for linear polarization and occurs in a cone for circular polarization. Since this transition is irreversible for a given polarization and does not occur for pulse durations below 100fs, we attribute this effect to stress-induced damage inside the crystal.

[1] Y.S. You et al., Nature Physics AOP (2016)

Q 3.2 Mon 10:45 K 0.023

Quasi-phase matched high harmonic generation in spatially structured Al plasmas — •Michael Wöstmann and Helmut Zacharias — Westfälische-Wilhelms Universität Münster, Physikalisches Institut, Wilhelm-Klemm-Straße 10, 48149 Münster

A route is presented in order to realize quasi-phase-matching of high-order harmonic generation in laser produced plasmas. This requires the spatial modulation of the plasma. A simple stack of thin target material (ca. 0.5 mm) and spacers is used in order to induce the modulation. The exact dimensions are derived by measuring the coherence lengths in unmodulated plasmas and the beam profile with respect to the focal position of the harmonic generating beam. The geometric phase advance of the fundamental radiation through its focus is found to be the governing parameter for resetting the phase of the emitted harmonic radiation between two slices of plasma. Applying four separated plasma plumes, an enhancement factor of 170 is observed for the 25th harmonic in relation to the maximal harmonic intensity generated in an unmodulated plasma of the same composition. The principle is expected to work even better at higher harmonic orders.

Q 3.3 Mon 11:00 K 0.023

2 μm doubly resonant paramatric oscillator pumped by a thin disk ultrashort laser — •Christian Markus Dietrich, Ihar Babushkin, Laura Rust, José Andrade, and Uwe Morgner — Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

Ultrafast light sources with a wavelength around two micrometers are interesting for several experiments like high harmonic generation and investigation of Brunel harmonics [1]. We want to present a doubly resonant optical parametric oscillator (DROPO) for intracavity experiments. Our system is pumped by a home built kerr lens mode locked Yb:YAG thin disk laser with a repetition rate of 34 MHz. The DROPO is operating in a bowtie configuration and uses a BBO as the nonlinear medium. An additional focus point inside the cavity is suitable for further experiments. The wavelength can be rapidly adjusted between the degeneracy point up to 1900 nm + 2300 nm by cavity length tuning alone.

[1] Babushkin, Brée, Dietrich, Demircan, Morgner & Husakou, J. Mod. Opt. Vol. 64 , Iss. 10-11, 2017

Q 3.4 Mon 11:15 K 0.023

Sub-10-fs visible pulses at 1MHz repetition rate from an optical-parametric amplifier — •Sven Kleinert[1], Ayhan Tajalli[1], Bernhard Kreipe[1], David Zuber[1], José R. C. Andrade[1], and Uwe Morgner[1,2,3] — [1]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany — [3]Hannoversches Zentrum für Optische Technologien, Leibniz Universiät Hannover, Nienburger Straße 17, 30167 Hannover, Germany

We present a compact optical-parametric amplification system (OPA) operating in the visible spectral range, delivering pulses with a Fourier-limited pulse duration below 10fs at a repetition rate of 1MHz. To this end, the output of a mode-locked chirped-pulse oscillator with cavity dumping is amplified in a single-stage rod-type fiber chirped-pulse amplifier delivering up to 40W of average power. These pulses enable the generation of energetic pump radiation for the OPA in the blue range, as well as a broadband supercontinuum seed in the visible spectral range. The OPA delivers more than 600nJ of pulse energy featuring a highly applicable source for different areas of strong-field studies where a high repetition rate is beneficial.

Q 3.5 Mon 11:30 K 0.023

Attosecond electron bunch creation in optical traveling waves via ponderomotive scattering — •Norbert Schönenberger, Martin Kozák, Timo Eckstein, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Many atomic, molecular and other condensed matter structures have not been fully studied yet at ultrafast timescales because adequate probing methods, like XUV, ultrafast electron diffraction and microscopy, are only now becoming available. Here, we report on the ponderomotive interaction of electrons with optical traveling waves and the ultrashort electron bunch trains generated after this interaction [1]. Such bunch trains could be the basis of such a probing method. In the interaction, the travelling waves are created by the superposition of two laser pulses at different frequencies intersecting at specific angles to ensure phase matching with the electrons. This technique allows for a strong energy modulation of the free electrons of 2.2 GeV/m. Even higher gradients could be achievable, as the ponderomotive force is only limited by the available laser power. Subsequent dispersive propagation of the electrons in free space causes ballistic microbunching on the sub cycle timescale. This bunching is detected via a second ponderomotive interaction at the temporal focus. Spectrograms recorded in this setup in conjunction with numerical simulations are used to determine that pulse trains of 300 as pulses are formed.

[1] Kozák, M., Eckstein, T., Schönenberger, N. & Hommelhoff, P., Nat. Phys. (2017), DOI: 10.1038/NPHYS4282.

Q 3.6 Mon 11:45 K 0.023

Strong-field-driven dispersive waves in gas-filled hollow-core fibres — •David Novoa[1], Felix Köttig[1], Francesco Tani[1], Marco Cassataro[1], Mehmet C. Günendi[1], John C. Travers[2], and Philip St.J. Russell[1] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Heriot-Watt University, Edinburgh, United Kingdom

The nonlinear parametric process of dispersive wave (DW) emission in gas-filled hollow-core photonic crystal fibres has been largely exploited as a means to efficiently generate tunable ultrafast radiation in the ultraviolet region, with a multitude of applications. The emission of DWs occurs in the normal dispersion regime of the fibre via nonlinear transfer of energy from a self-compressed soliton spectrally located in the anomalous dispersion region, a process that relies crucially on phase matching to be efficient. However, this picture becomes richer when the self-compression dynamics of the pump pulse is taken into account. In particular, peak intensity levels high enough to partially ionize the filling gas can be attained owing to the high damage threshold of these fibres, opening access to in-fibre strong-field dynamics. Thus, it was recently predicted that, in the strong-field regime, the additional transient anomalous dispersion introduced by gas ionization may enable resonant excitation of DWs in the mid-infrared, a forbidden process in the absence of free electrons. Here we report the experimental observation of such strong-field-driven mid-infrared DWs, embedded in a 4.7-octave-wide spectrum that uniquely reaches simultaneously to the vacuum ultraviolet, with 1.7 W of total average power.

Q 3.7 Mon 12:00 K 0.023

Long-Lived Index Changes Induced by Femtosecond Ionization in Ar-Filled Hollow-Core PCF — •Johannes R. Köhler, Francesco Tani, Barbara M. Trabold, Felix Köttig, Mallika I. Suresh, and Philip St.J. Russell — Max-Planck-Institut für die Physik des Lichts, Erlangen, Deutschland

Gas-filled hollow-core photonic crystal fibre (HC-PCF) is finding important applications in ultrafast nonlinear optics, for example for pulse compression down to single cycles and for generation of broadband tunable radiation in the deep and vacuum ultraviolet. Scaling these novel light sources to MHz repetition rates is enabled by exploiting the large damage threshold in HC-PCFs that guide light by anti-resonant reflection (ARR) in the cladding. At the same time, they offer small core diameters, making it possible to access strongly nonlinear effects such as gas ionisation, using femtosecond pulses with energies of only a few μJ. When a plasma forms, each pulse causes a transient refractive index change that, if sufficiently long-lived, may affect the propagation of subsequent pulses. Here we investigate the effects of ionization, caused by self-compressed femtosecond pulses, on the temporal refractive index evolution in an argon-filled ARR-PCF. To this end we focus CW probe light transversely through the fiber cladding into the core and follow its transient phase-shifts over time using a fibre-based Mach-Zehnder interferometer. The results reveal long-lived ionisation-induced refractive index changes decaying over $\sim$25 μs and indicate that interactions among pulses, so far disregarded in HC-PCFs, will occur at repetition rates as low as 40 kHz.

Q 3.8 Mon 12:15 K 0.023

Micro-sized synthesis of customized 3D GRadient INdex elements by femtosecond laser lithography — Neus Oliver, •Alejandro Jurado, and Cornelia Denz — Institut für Angewandte Physik (WWU Universität) Münster, Germany

Increasing interest in micro-scale optics has led to the development of novel miniaturization techniques, among which laser lithography stands out as a powerful approach. Laser lithography allows the design and synthesis of arbitrary geometries to act as lenses, waveguides or diffractive components. Advances in this field have been focused, not only on improving the spatial resolution, but also on tuning the optical properties of the structures, such as the refractive index (RI). Specifically, elements with a spatial variation of the local RI can be obtained (GRadient INdex). The dependence of the attained RI with the exposure parameters in various polymers has been addressed, enabling the realization of 2D and multilayered GRIN structures. In this work, hybrid polymer Ormocomp is used to fabricate GRIN micro-structures via femtosecond laser lithography based on two-photon polymerization (TPP). We characterize the RI of our samples with phase maps obtained through interferometry and Fourier analysis methods. As calibration, the relation between laser power and the RI is studied. With our procedure, 3D GRIN distributions down to tens of micrometers can be achieved. We complement our results with ray tracing simulations for optimization of GRIN design. Our approach represents a comprehensive and versatile strategy for the tailored fabrication of 3D GRIN micro-optical systems, in which the downscaling is foreseen.

Q 3.9 Mon 12:30 K 0.023

Real time Dynamics of Femtosecond Soliton Molecules — •Georg Herink[1], Felix Kurtz[2], Claus Ropers[2] und Daniel Solli[3] — [1]Universität Bayreuth, Bayreuth, Deutschland — [2]Universität Göttingen, Göttingen, Deutschland — [3]UCLA, Los Angeles, USA

Femtosecond lasers feature bound states of ultrashort pulses, known as Soliton molecules. The rapid internal motion of such bound states can be resolved in real-time based on the time-stretch dispersive Fourier transformation. We present the initial binding of soliton molecules and resolve several classes of bound state dynamics, ranging from highly regular to stochastic trajectories. The underlying mechanisms are discussed and implications for novel states of laser operation are highlighted.

Q 4: Matter Wave Optics I

Time: Monday 10:30–12:30 Location: K 1.013

Q 4.1 Mon 10:30 K 1.013

Compact diode laser system for dual-species atom interferometry with Rb and K in space — •Oliver Anton[1], Klaus Döringshoff[1], Vladimir Schkolnik[1], Simon Kanthak[1], Benjamin Wiegand[1], Moritz Mihm[3], Ortwin Hellmig[4], André Wenzlawski[3], Patrick Windpassinger[3], Markus Krutzik[1,2], Achim Peters[1,2], and The MAIUS Team[1,2,3,4,5,6] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]Institut für Physik, JGU Mainz — [4]ILP, Universität Hamburg — [5]ZARM, Universität Bremen — [6]IQO, Leibniz Universität Hannover

The MAIUS 2/3 missions will perform dual-species atom interferometry with BEC's onboard sounding rockets, enabling longer, uninterupted timescales of microgravity than any ground based facility. As a result of increasing microgravity times beyond the typical earthbound limits, future missions with dual-species atom interferometry will allow for high-precision tests of Einsteins's Equivalence principle. This talk presents the design of our laser system for this mission in detail and shows first performance test results. The laser sources are extended cavity diode laser (ECDL), master oscillator power amplifier (MOPA) modules emitting at wavelengths of 780 nm and 767 nm for Rb and K as well as 1064 nm for a dipole trap. Key components such as micro-integrated high power diode lasers, optical fiber splitter system and Zerodur benches will be presented.

This work is supported by the German Space Agency (DLR) sponsored by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WP1432.

Q 4.2 Mon 10:45 K 1.013

An optical dipole trap for dual-species atom interferometry with K and Rb in space — •Simon Kanthak[1], Klaus Döringshoff[1], Martina Gebbe[2], Sven Abend[3], Matthias Gersemann[3], Markus Krutzik[1], Achim Peters[1], and The MAIUS Team[1,2,3,4,5] — [1]Institut für Physik, HU zu Berlin — [2]ZARM, Universität Bremen — [3]IQ, LU Hannover — [4]Institut für Physik, JGU Mainz — [5]Ferdinand-Braun-Institut, Berlin

An important challenge for dual-species atom interferometry experiments is the preperation of the quantum probes entering the interferometer which, amongst others, requires precise control of the relative center-of-mass positions. In the MAIUS 2/3 sounding rocket missions, a mixture of Rubidium and Potassium is initially trapped and cooled in an atom chip based trap and then transferred into an optical dipole trap (ODT), which allows for tuning of the collisional properties via Feshbach resonances and optical delta kick collimation for both species.

We present the ODT laser system at 1064 nm for the MAIUS 2/3 payload. It is based on a microintegrated extended cavity diode laser, master oscillator power amplifer (ECDL-MOPA) module. We report in detail on design and performance of our flight-qualified, all-fibered system including acusto-optical modulator and optical switch, as well as on results of loading a BEC from an atom chip based trap into the dipole trap and systematic studies of the transfer efficiency.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WP1432.

Q 4.3 Mon 11:00 K 1.013

Compact and stable potassium laser system for dual speciesatom interferometry in microgravity — •Julia Pahl[1], Julien Kluge[1], Aline N. Dinkelaker[1], Christoph Grzeschik[1], Markus Krutzik[1], Achim Peters[1,2], and The QUANTUS Team[1,3,4,5,6,7] — [1]HU Berlin — [2]FBH Berlin — [3]U Bremen — [4]LU Hannover — [5]JGU Mainz — [6]U Ulm — [7]TU Darmstadt

The QUANTUS-2 apparatus is performing atom-chip based rubidium BEC experiments at the drop tower in Bremen. For future dual species experiments in microgravity, we developed and qualified a laser system for potassium 41 which meets the drop tower's demands of mass, size and robustness. This is achieved by high-power, micro-integrated distributed-feedback laser diodes, miniaturized opto-mechanics as well as compact electronics that provide the necessary driving and control capabilities. In this talk we present the design of our diode laser system, discuss the performance and functionality as well as the latest results of the first campaigns.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1552-1557.

Q 4.4 Mon 11:15 K 1.013

Simulation of Bose-Einstein condensates in accelerated Bloch lattices towards large momentum transfer atom interferometers — •Jan-Niclas Siemss[1], Ernst Maria Rasel[2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Large momentum transfer (LMT) schemes for atom interferometry increase the spatial separation of the two interferometer arms enhancing the sensitivity of such atomic detectors. Alternatively, one would employ large interrogation times in microgravity[1] and fountains[2].

Novel LMT schemes for atom interferometry combine Bragg pulses and Bloch oscillations in optical lattices to coherently split and recombine the atomic wave packets.

The use of delta-kick collimated Bose-Einstein condensates is crucial as the performance of such an interferometer is limited by the fidelity of the LMT atom-light interaction which is constrained by the finite momentum width of the atomic ensemble and tunneling to higher-order bands of the optical lattice.

In our work, we simulate interferometric sequences involving Bose-Einstein condensates driven by symmetric optical lattices to interpret and optimize pioneering experiments performed in the QUANTUS collaboration. To this end, a time-dependent Gross-Pitaevskii model is developed and adapted to typical experimental environments.

[1]H. Müntinga et al. Phys. Rev. Lett. 110, 093602 (2013)
[2]S. M. Dickerson et al. Phys. Rev. Lett. 111, 083001 (2013)

Q 4.5 Mon 11:30 K 1.013

Light-pulse atom interferometry with ultracold thermal clouds and realistic laser pulses — •Jens Jenewein, Albert Roura, Wolfgang P. Schleich, and the QUANTUS team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, D-89069 Ulm

Using our real-time simulation of Mach-Zehnder light-pulse atom interferometry, we investigate results of ground experiments with lensed thermal states carried out with the QUANTUS-1 device. We apply data analysis methods to the evaluation of the experimental data and compare them with our simulated results. Because our simulation incorporates the effects of realistic laser pulses (i.e. velocity selectivity and off-resonant diffraction orders), it is particularly suitable for the description of these interferometry experiments. This feature can be exploited to investigate in detail how the combination of delta-kick collimation with different amounts of evaporative cooling affects the contrast and the sensitivity of the interferometric measurements, which is also influenced by the total atom number.

The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1556.

Q 4.6 Mon 11:45 K 1.013

Controlling the directionality and the quantum-to-classical transition of a quantum walk in momentum space — •Alexander Gresch[1], Siamak Dadras[2], Caspar Groiseau[1], Gil S. Summy[2], and Sandro Wimberger[3,4,1] — [1]ITP, Heidelberg University, Philosophenweg 12, 69120 Heidelberg, Germany — [2]Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078-3072, USA — [3]Dipartimento di Scienze Matematiche, Fisiche ed Informatiche, Università di Parma, Parco Area delle Scienze 7/A, 43124 Parma, Italy — [4]INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, Parma, Italy

Randomness is the crucial characteristics in a huge variety of phenomena ranging from Brownian motion to game theory. Its quantum counterpart might play a key role in quantum computation algorithms as it intrinsically differs due to its quantum features: interference and entanglement. Both resources are featured in quantum walks. They use entanglement to determine the walker's direction of motion. Several proof-of-principle experiments have already been conducted for quantum walks, our walk scheme, however, features robustness and controllability as they stem from the synthesis of the well-studied atom-optics kicked rotor with a quantum ratchet for the ballistic states dynamics. Our quantum walk is realized in momentum space using a BEC. This very feature guarantees controllability and possibly an expansion to higher walk dimensions and to investigations of many-body correlations.

Q 4.7 Mon 12:00 K 1.013

Quantum Interference of Force — •Raul Corrêa[1,2], Marina F. B. Cenni[1], and Pablo L. Saldanha[1] — [1]Departamento de Física, Universidade Federal de Minas Gerais, Caixa Postal 701, 30161-970, Belo Horizonte, MG, Brazil — [2]Institute für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

We discuss how, due to an interference effect, the superposition of a positive force with a null force on a quantum particle may result in a negative momentum transfer to the particle when the appropriate post-selection is made. This quantum interference of force represents a novel manifestation of the wave-particle duality, since forces act on particles and interference is a property of waves. We discuss two experimental schemes that could verify the effect with current technology: one with quantum particles (electrons, atoms or neutrons) in a Mach-Zehnder interferometer in free space, and another with atoms from a Bose-Einstein condensate.

Q 4.8 Mon 12:15 K 1.013

Spherical aberration correction in a scanning transmission electron microscope using a sculpted thin film — •Roy Shiloh[1,3], Roei Remez[1], Peng-Han Lu[2], Lei Jin[2], Yossi Lereah[1], Amir H. Tavabi[2], Rafal E. Dunin-Borkowski[2], and Ady Arie[1] — [1]School of Electrical Engineering, Fleischman Faculty of Engineering, Tel Aviv University, Tel Aviv, Israel — [2]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons and Peter Grünberg Institute, Forschungszentrum Jülich, Jülich, Germany — [3]Currently at: Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany

Nearly eighty years ago, Scherzer showed that rotationally symmetric, charge-free, static electron lenses are limited by an unavoidable, positive spherical aberration. A major breakthrough in the spatial resolution of electron microscopes was reached two decades ago by abandoning the first of these conditions, with the success of multipole aberration correctors. Here, we use a refractive silicon nitride thin film acting as a diffractive optical element for free electron beams, to tackle the second of Scherzer's constraints and demonstrate an alternative method for correcting spherical aberration in a scanning transmission electron microscope. We reveal features in Si and Cu samples that cannot be resolved in an uncorrected microscope. Our thin film corrector can be implemented as an immediate low cost upgrade to existing microscopes without re-engineering of the column or complicated operation protocols, can correct additional aberrations and may be useful in other beamline schemes such as particle accelerators and free electron lasers.

Q 5: Precision Spectrosocopy I - trapped ions (joint session A/Q)

Time: Monday 10:30–12:00 Location: K 1.016

Invited Talk Q 5.1 Mon 10:30 K 1.016

Segmented ion traps with integrated solenoids for scalable microwave based QIP — •Michael Johanning, Timm F. Gloger, Peter Kaufmann, Hendrik Siebeneich, and Christof Wunderlich — Faculty of Science and Technology, Department of Physics, University of Siegen, 57068 Siegen, Germany

Segmented traps have proven to be an essential ingredient for quantum information processing (QIP) using cold trapped ions, as they allow to control the position and shape of ion crystals, even in a time dependent fashion, and can be used to relocate or reshape ion crystals for transport, splitting and merging operations and tune normal modes and distances, e. g. to create strings of equidistant ions.

On the other hand, microwave manipulation has shown to be a way for internal state manipulation with near unit fidelity without requiring sub-Doppler cooling. Additional position dependent fields allow for high fidelity addressing and create an effective spin-spin coupling that can be used to create entangled states. The combination of segmented traps and magnetic gradient induced coupling (MAGIC) allows for tuning of coupling constants, e. g. to create long distance entanglement and thus facilitates scalable quantum simulations.

We give an overview over our ongoing projects which combine segmented microtraps with micro-structured solenoids. Experimental results obtained in such traps include robust Hahn Ramsey interferometry, high fidelity transport of internal states, and single ion addressing.

Q 5.2 Mon 11:00 K 1.016

Trapping of anions for laser cooling — •Pauline Yzombard, Alban Kellerbauer, and Giovanni Cerchiari — Max Planck Institut für Kernphysik, Heidelberg, Germany

There is only a very small number of anions candidates with an optical dipole-allowed transition between two bound states that are potentially suitable for Doppler laser cooling. Detailed spectroscopic studies were needed to identify a proper candidate [1].

According to our latest results, the La- ion seems promising [2]. But the narrow width of its bound-bound transition implies a long interaction time for the laser cooling to take place. We have developed two traps, a cryogenic Penning trap and a room-temperature linear Paul trap, to trap the anions long enough to apply laser cooling. As the efficient Doppler laser cooling of La- would require pre-cooling, we are currently developing an evaporative cooling step assisted by laser excitation.

One of the main motivations for this work is the importance of an ultra-cold negative plasma for antimatter experiments. The established technique for antihydrogen formation is based on merging antiproton and positron plasmas at low energy. The ability of sympathetically cooling the antiprotons with laser-cooled anions would open the path to new precision measurements with antihydrogen [3].

[1] U.Warring et al. PRL 102 (2009) 043001. [2] E. Jordan and al. PRL 115 (2015) 113001 [3] A. Kellerbauer New J. Phys. 8 (2006) 45. 2005

Q 5.3 Mon 11:15 K 1.016

Sympathetic cooling of OH- by a laser-cooled buffer gas — •Jonas Tauch[1], Henry Lopez[1], Jan Trautmann[1], Bastian Höltkemeier[1], Eric Endres[1], Roland Wester[3], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Deutschland — [2]University of Science and Technology of China, Shanghai Branch, Shanghai 201315, China — [3]Institut f. Ionenphysik und angewandte Physik, Universität Innsbruck, Österreich

Sympathetic cooling has become a powerful and universal method for preparing ultracold ions confined in radio frequency traps. In the past few year there has been a large debate about the limitations of this method. We recently developed a theoretical description which predicts that this limitations can be overcome by a localized buffer gas cloud and/or a higher order radio frequency trap. In this talk I present the recent results of our hybrid trap system, consisting of an 8-pole radio frequency trap and a dark spontaneous-force optical Rubidium trap. For probing the temperature of the ions, in particular OH-, we apply photodetachment tomography and time-of-flight detection of ions extracted from the trap. Via photodetachement spectroscopy we can also detect the energy distribution in the internal degree of freedom. We observe first evidence for sympathetic cooling and deviations from a thermal distribution of the ions, as predicted by our theoretical model.

Q 5.4 Mon 11:30 K 1.016

Electronic coupling of laser-cooled ions stored in different traps — •Raúl A. Rica[1,2], Francisco Domínguez[1], Íñigo Arrazola[3], Javier Bañuelos[1], Manuel J. Gutiérrez[1], Lucas Lamata[3], Jesús J. del Pozo[1], Enrique Solano[3,4,5], and Daniel Rodríguez[1,2] — [1]Departamento de Física Atómica, Molecular y Nuclear, Universidad de Granada, 18071, Granada, Spain. — [2]Centro de Investigación en Tecnologías de la Información y las Comunicaciones, Universidad de Granada, 18071, Granada, Spain. — [3]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080, Bilbao, Spain. — [4]IKERBASQUE, Basque Foundation for Science, María Díaz de Haro 3, 48011, Bilbao, Spain. — [5]Department of Physics, Shanghai University, 200444 Shanghai, People's Republic of China.

A single laser-cooled ion stored in an ion trap can be used as an ultrasensitive detector of RF electric fields of diverse origin. One of the most appealing applications of such a detector considers its coupling to another oscillator. In this case, the ion can be used as a coolant for the second system, and even a quantum state transfer between them can be envisioned. In this contribution, we report on the evaluation of the sensitivity of a single Doppler-cooled ion in a Paul trap to external electric fields. We also present our progress in the implementation of a novel double trap system where two laser-cooled ions or clouds of ions can be coupled through the electric currents they induce on a common electrode.

Q 5.5 Mon 11:45 K 1.016

Coulomb Coupling of Single Ions in a 2D Trap Array — •Frederick Hakelberg, Philip Kiefer, Sebastian Schnell, Matthias Wittemer, Jan-Philip Schroeder, Ulrich Warring, and Tobias Schaetz — University of Freiburg, Germany

Trapped ions present a promising system for quantum simulations [1]. Surface-electrode traps in contrast to conventional ion traps offer the advantage of scalability to larger system size and dimension while maintaining individual control: Dedicated radio-frequency electrode shapes allow the creation of two-dimensional trap arrays [2] while control electrodes allow localized manipulation of the trapping potential tuning motional frequencies and mode orientations [3,4]. The coupling between the individual ions, seen as harmonic oscillators, can be mediated via the Coulomb interaction, as has been demonstrated for one-dimensional traps [5].

In our experiment we trap Mg^+ ions in an equilateral triangle with $40\,\mu$m ion-ion distance. We present first experimental results for Coulomb coupling between ions in this two-dimensional trap array. Furthermore we investigate the effect of anharmonicities of the trapping potential on the exchange of large coherent states.

[1] T. Schaetz *et al.*, New J. Phys. **15**, 085009 (2013)
[2] R. Schmied *et al.*, Phys. Rev. Lett. **102**, 233002 (2009)
[3] M. Mielenz *et al.*, Nature Communications **7**, 11839 (2016)
[4] H. Kalis *et al.*, Phys. Rev. A **94**, 023401 (2016)
[5] Brown *et al.* & Harlander *et al.*, Nature **471**, 196-203 (2011)

Q 6: Quantum Information (Concepts and Methods) I

Time: Monday 10:30–12:30 Location: K 1.019

Group Report Q 6.1 Mon 10:30 K 1.019

Quantum teleportation via electron-exchange collisions — •Bernd Lohmann[1,2], Karl Blum[2], and Burkhard Langer[3] — [1]The Hamburg Centre For Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Straße 9, 48149 Münster, Germany — [3]Physikalische Chemie, Freie Universität Berlin, Takustraße 3, 14195 Berlin, Germany

In recent research [1,2], we have shown that strong correlations exist in elastic electron-exchange collisions of light hydrogen-like atoms, violating Bell's inequalities significantly, which allows for generating tunable spin pairs with any desired degree of entanglement. Utilizing our tunable entanglement resource, we will discuss the possibility of performing quantum teleportation with free massive particles applying a twofold elastic electron-exchange scattering. In a first collision, an unpolarized electron will be scattered on an unpolarized atom, generating an entangled electron–atom pair. Subsequently, in a second scattering, an arbitrarily polarized electron will collide with the entangled atom thereby generating interference which allows for teleporting the degree of spin polarization onto the former unpolarized electron. We will demonstrate the feasibility of such experiments.

[1] Blum K., and Lohmann, B., *Phys. Rev. Lett.* **116**, 033201 (2016).
[2] Lohmann, B., Blum, K., and Langer, B., *Phys. Rev. A* **94**, 032331 (2016).

Q 6.2 Mon 11:00 K 1.019

The Computational Complexity of Multiboson Correlation Interference — •Simon Laibacher[1] and Vincenzo Tamma[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, D-89069 Ulm — [2]Faculty of Science, SEES, University of Portsmouth, Portsmouth PO1 3QL, UK

Multiboson correlation sampling was introduced in [1] as a modification of boson sampling [2] in which the photons are detected in a temporally or spectrally resolved manner. Later, it was demonstrated that this problem remains classically hard when nonidentical photons are used, even if they are fully distinguishable in time or frequency at the input [3].

We show that this robustness of the computational complexity persists even if the distinguishability of the photons at the input is random between consecutive runs of the sampling experiment. This feature can be exploited to improve experimental implementations of sampling problems and to significantly simplify the upscaling of such setups to larger photon numbers.

[1] V. Tamma, S. Laibacher, Phys. Rev. Lett. **114**, 243601 (2015).
[2] S. Aaronson, A. Arkhipov, in: *Proceedings of the 43rd annual ACM symposium on Theory of computing* (ACM, 2011) pp. 333–342.
[3] S. Laibacher, V. Tamma, Phys. Rev. Lett. **115**, 243605 (2015).

Q 6.3 Mon 11:15 K 1.019

Ultra-low vibration closed-cycle cryogenic surface-electrode ion trap setup — •Sebastian Grondkowski[1], Timko Dubielzig[1], Fabian Ude[1], Giorgio Zarantonello[1,2], Henning Hahn[1,2], Martina Wahnschaffe[2,1], Amado Bautista-Salvador[2,1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig

Operation of ion traps at cryogenic temperatures is highly benefitial to fight the effects of anomalous motional heating, obtain excellent electrical properties of materials and achieve long trap lifetimes [1-3]. When using a closed-cycle cryostat to cool the apparatus, excessive vibrations associated with the mechanical motion of the cooler should be avoided in order not to affect the optical addressing of the ions adversely. We discuss a mechanical suspension for a commercial vibration isolation interface that allows easy alignment and long term stability of the setup. We present an interferometric approach to determine the residual movement of the cold head and find that for suitable temperatures of the cold stage, we can place an upper limit of 8 nm RMS on the vibration level, limited by the performance of the interferometer.

[1] J. Chiaverini and J. M. Sage, PRA 89, 012318 (2014)
[2] S. W. Van Sciver, Helium Cryogenics, 2nd ed., Springer (2012)
[3] D. Gandolfi et al., Rev. Sci. Instr. 83, 084705 (2012)

Q 6.4 Mon 11:30 K 1.019

Exclusion principles for hard-core bosons — •Macauley Davy[1], Felix Tennie[1], Vlatko Vedral[1,2], and Christian Schilling[1] — [1]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom — [2]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543

The particle exchange symmetry strongly shapes the behavior of quantum systems even in the one-particle picture: While fermionic occupation numbers obey Pauli's exclusion principle, bosons can multiply occupy any one-particle quantum state $|\varphi\rangle$ and even form a Bose-Einstein condensate. One may therefore wonder how the situation looks like for hard-core bosons, fulfilling mixed commutation relations. We first observe that for arbitrary systems of N hard-core bosons on d lattice sites the maximal possible occupation number is given by $N_{max} = (N/d)(d - N + 1)$ which is smaller than N but larger than 1. N_{max} can only be achieved for states $|\varphi\rangle$ which are maximally unbiased w.r.t. the lattice site basis $\{|j\rangle\}_{j=1}^{d}$ ("momentum states") and when the total system is maximally delocalized. We generalize this result by relating the maximal occupation number $N_{max}^{(\varphi)}$ of a fixed one-particle state $|\varphi\rangle = \sum_{j=1}^{d} c_j |j\rangle$ to the unbiasedness of $|\varphi\rangle$ w.r.t. to the basis of lattice site states.

Q 6.5 Mon 11:45 K 1.019

Universal extensions of restricted classes of quantum operations - a group theoretic approach — Michal Oszmaniec[1] and •Zoltán Zimborás[2] — [1]Quantum Information Centre of Gdansk, 81-824 Sopot, Poland — [2]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

For numerous applications of quantum theory it is desirable to be able to apply arbitrary unitary operations on a given quantum system. However, in particular situations only a subset of unitary operations is easily accessible. This raises the question: what additional unitary gates should be added to a given gate-set in order to attain physical universality? In this talk, I will present our recent results on this for three paradigmatic cases: (A) particle-number preserving bosonic linear optics, (B) particle-number preserving fermionic linear optics, and (C) general (not necessarily particle-number preserving) fermionic linear optics. Using recently developed group theoretic tools, we could classify, in each of these scenarios, what sets of gates are generated, if an additional gate is added to the set of allowed transformations [1].

[1] M. Oszmaniec, Z. Zimborás, Phys Rev. Lett. 119, 220502 (2017).

Q 6.6 Mon 12:00 K 1.019

Reconstructing quantum states from single-party information — •Christian Schilling[1], Carlos Benavides-Riveros[2], and Peter Vrana[3] — [1]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle, Germany — [3]Department of Geometry, Budapest University of Technology and Economics, Budapest, Hungary

The possible compatibility of density matrices for single-party subsystems is described by linear constraints on their respective spectra. Whenever some of those quantum marginal constraints are saturated, the total quantum state has a specific, simplified structure. We prove that these remarkable global implications of extremal local information are stable, i.e. they hold approximately for spectra close to the boundary of the allowed region. Application of this general result to fermionic quantum systems allows us to characterize natural extensions of the Hartree-Fock ansatz and to quantify their accuracy by resorting to one-particle information, only: The fraction of the correlation energy not recovered by such an ansatz can be estimated from above by a simple geometric quantity in the occupation number picture.

Q 6.7 Mon 12:15 K 1.019

Natural extensions of Hartree-Fock based on extremal one-particle information — •Carlos L. Benavides-Riveros[1] and Christian Schilling[2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle, Germany — [2]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom

One-particle density matrices are compatible with pure N-fermion quantum states whenever their spectra (natural occupation numbers) lie in the polytope defined by the generalized Pauli constraints. We characterize existing and propose novel extensions of the Hartree-Fock ansatz by referring to the different facets of that polytope. Moreover, we derive a quantitative relation between the accuracy of those variational ansatzes and the distance of the exact ground state's occupation number vector to the respective polytope facets. In an extensive numerical study those ansatzes are tested and we explain how a geometrical hierarchy of the polytope allows one to systematically recover all static correlation energy.

Q 7: Quantum Information (Quantum Computing)

Time: Monday 10:30–12:30 Location: K 1.020

Group Report Q 7.1 Mon 10:30 K 1.020

Speeding-up the decision making of a learning agent using an ion trap quantum processor — •Theeraphot Sriarunothai[1], Sabine Wölk[2,1], Gouri Shankar Giri[1], Nicolai Friis[3,2], Vedran Dunjko[2,4], Hans Briegel[2,5], and Christof Wunderlich[1] — [1]Department Physik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany — [2]Institute for Theoretical Physics, University of Innsbruck, Technikerstraße 21a, 6020 Innsbruck, Austria — [3]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmangasse 3, 1090 Vienna, Austria — [4]Max Planck Institute of Quantum Optics Garching 85748, Germany — [5]Department of Philosophy, University of Konstanz, 78457 Konstanz, Germany

We report a proof-of-principle experimental demonstration of the quantum speed-up for learning agents utilizing a small-scale quantum information processor based on radiofrequency-driven trapped ions [1]. The decision-making process of a quantum learning agent within the projective simulation paradigm for machine learning is implemented in a system of two qubits. The latter are realized using hyperfine states of two frequency-addressed atomic ions exposed to a static magnetic field gradient. We show that the deliberation time of this quantum learning agent is quadratically improved with respect to comparable classical learning agents. The performance of this quantum-enhanced learning agent highlights the potential of scalable quantum processors taking advantage of machine learning.

[1] Th. Sriarunothai et al., arXiv: 1709.01366 (2017)

Q 7.2 Mon 11:00 K 1.020

Automatisierte Positionskontrolle von Ionen in einer segmentierten Paulfalle — •Janine Nicodemus, Thomas Ruster, Vidyut Kaushal, Daniël Pijn, Björn Lekitsch, Ulrich Poschinger und Ferdinand Schmidt-Kaler — Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Eine Möglichkeit zur Realisierung eines skalierbaren Quantenprozessors beruht auf Positionierung von Ionen in segmentierten Paulfallen [1]. Um einzelne Ionen anzusprechen und Zwei-Qubit-Verschränkungsoperationen zwischen spezifischen Ionen durchzuführen, werden verschiedene Bewegungsoperationen benötigt, wie z.B. der Transport von Ionen zwischen Speicher- und Laserinteraktionszonen [2] und die Ionenkristalltrennung [3]. Die zunehmende Komplexität der Sequenzen, beispielsweise bei der Verschränkung von vier Qubits [4], und der langreichweitige Einfluss der Fallenelektroden auf das Potential an entfernten Fallensegmenten fordern eine Optimierung der Bewegungsoperationen unter Einbeziehung aller gespeicherten Ionen und Fallensegmente. Wir stellen ein Software Framework zur automatisierten Erzeugung von optimierten Spannungskonfigurationen für Multi-Qubit-Register Bewegungsoperationen in einer segmentierten Paulfalle vor und zeigen die Verbesserungen anhand experimenteller Resultate.

[1] D. Kielpinski et al., Nature 417, 709-711 (2002)
[2] A. Walther et al., Phys. Rev. Lett. 109, 080501 (2012)
[3] T. Ruster et al., Phys. Rev. A 90, 033410, 033410 (2014)
[4] H. Kaufmann et al., Phys. Rev. Lett. 119, 150503 (2017)

Q 7.3 Mon 11:15 K 1.020

Investigation of surface noise in high-temperature superconducting surface ion traps — •Philip Holz[1], Kirill Lakhmanskiy[1], Dominic Schärtl[1], Muir Kumph[2], Ben Ames[1], Reouven Assouly[1], Yves Colombe[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Uni Innsbruck, Österreich — [2]IBM, Thomas J. Watson Research Center, USA — [3]Institut für Quantenoptik und Quanteninformation, Innsbruck, Österreich

Ion traps are a promising platform for quantum computation. One approach to scale up to larger numbers of qubits is to utilize microfaricated ion traps [1]. The close proximity of the ions to the trap surface leads, however, to an increase of the motional heating rate, which degrades the fidelity of quantum operations. The origin of this heating is not well understood [2]. Here we report on heating rate measurements performed in surface ion traps made of YBCO, a high-temperature superconductor. One trap is designed in such a way that Johnson noise is the dominant source of motional heating above the critical temperature T_c. By lowering the trap temperature below T_c we can directly compare Johnson noise with surface noise. Interestingly, for $T < T_c$ the frequency scaling of the heating rate shows deviations from a simple power law behavior as predicted by so called two-level fluctuator models. In a second trap we observe a clear plateau in the temperature dependence of the heating rate for temperatures $T > T_c$, which has not been observed so far. [1] R. Blatt and D. Wineland, Nature 453, 1008 (2008) [2] M. Brownnutt et al., Rev. Mod. Phys. 87, 1419 (2015)

Q 7.4 Mon 11:30 K 1.020

A Statistical Analysis of Tunable Quantum Annealing Devices — •Jonathan Brugger — Albert-Ludwigs-Universität Freiburg

Tunable quantum annealing devices (such as the D-Wave 2000Q) have recently gained growing attention and popularity since they have demonstrated to allow a quantum speedup for some complex computational problems and are believed to be valuable for many applications in machine learning and optimization problems in the near future. We present a statistical analysis to estimate the fidelity of such computations, and quantify the scaling behaviour of our results with the size of the machine's quantum register.

Q 7.5 Mon 11:45 K 1.020

Anti-concentration theorems for schemes showing a quantum speedup — •Dominik Hangleiter, Juan Bermejo-Vega, Martin Schwarz, and Jens Eisert — FU Berlin, Fachbereich Physik, Arnimallee 14, 14195 Berlin

Demonstrating a quantum speedup in as simple a setting as possible is a key milestone in the development of quantum technologies. Within the last year, achieving this milestone has come into close reach, in part but not only due to the quantum computing programmes of IBM and Google. At the heart of any task suitable for demonstrating a quantum speedup lies a complexity-theoretic proof that a quantum device computationally outperforms any classical device. Most proposals for near-term devices are based on sampling from some probability distribution. The technique most often used to prove a speedup for such tasks in that require certain complexity-theoretic conjectures about the sampled distribution to be assumed, one of them being that the distribution 'anti-concentrates'. In this talk we will prove this conjecture for unitary two-designs which covers many interesting settings that are based on random quantum circuits including, most prominently, random universal circuits.

Q 7.6 Mon 12:00 K 1.020

Correlated Noise in Quantum Circuits — •Markus Heinrich and David Gross — Institut für theoretische Physik, Universität zu Köln

The celebrated quantum threshold theorem guarantees the existence of a, however unknown, noise threshold for arbitrary-precision quantum computing and, as such, is the foundation of fault-tolerant quantum computation. Here, we follow a path laid out by Buhrman et al. and Virmani to derive upper bounds on this threshold by computing the amount of noise needed to efficiently simulate any quantum circuit on a classical computer. In contrast to former work, we derive a general theoretical framework which captures most of the known noise models, including correlated noise. This allows us to study the effects of noise in more detail and to give tighter upper bounds on the error correction threshold.

Q 7.7 Mon 12:15 K 1.020

Fault-tolerant interface between quantum memories and quantum processors — •Hendrik Poulsen Nautrup[1], Nicolai Friis[1,2], and Hans J. Briegel[1] — [1]Institute for Theoretical Physics, University of Innsbruck, Technikerstr. 21a, 6020 Innsbruck, Austria — [2]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria

Quantum computation holds the promise to solve computational problems believed to be unsolvable on classical computers. Yet, before we can discuss solving problems on a quantum computer, we have to be able to build one. The major obstacles for any near-term implementation are noise and decoherence. Thus, in order to protect quantum computations from the deteriorating effects of noise, we need to encode qubits into error correction codes. And different codes can serve different purposes: Some codes will be the basis for a quantum memory, others that of a processor. To exploit the particular advantages of different codes for fault-tolerant quantum computation, it is necessary to be able to switch between them. We propose a practical solution, subsystem lattice surgery, which requires only two-body nearest neighbor interactions in a fixed layout in addition to the indispensable error correction. This method can be employed to create a simple interface, a quantum bus, between noise resilient surface code memories and flexible color code processors in a near-term implementation.

Q 8: Ultracold Plasmas and Rydberg Systems I (joint session Q/A)

Time: Monday 10:30–12:15 Location: K 2.013

Group Report Q 8.1 Mon 10:30 K 2.013

A Photon-Photon Quantum Gate Based on Rydberg Polaritons — •Steffen Schmidt-Eberle, Daniel Tiarks, Thomas Stolz, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Rydberg polaritons offer a unique way to create strong interactions for photons. We utilize these interactions to demonstrate a photon-photon quantum gate. To achieve this, a photonic control qubit is stored in a quantum memory consisting of a superposition of a ground state and a Rydberg state in an ultracold atomic gas. This qubit interacts with a photonic target qubit in the form of a propagating Rydberg polariton to generate a conditional pi phase shift, as in Ref. [1]. Finally, the control photon is retrieved. We measure two controlled-NOT truth tables and the two-photon state after an entangling-gate operation. This work is an important step toward applications in optical quantum information processing, such as deterministic photonic Bell-state detection which is crucial for quantum repeaters.

[1] D. Tiarks et al., Science Advances 2, 1600036 (2016).

Q 8.2 Mon 11:00 K 2.013

Excitation blockade in highly Stark-shifted Rydberg states — •Raphael Nold, Markus Stecker, Lea Steinert, József Fortágh, and Andreas Günther — Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen

We report on the observation of excitation blockade for strongly Stark-shifted Rydberg states. Therefore, we make use of the fact that even for electric fields above the classical ionization limit, there are long-living Rydberg states with small ionization rates. We have developed a detection scheme for controlled ionization and magnified imaging of those states with high spatial and temporal resolution by adiabatic transfer to a state with a suitable ionization rate. The detector consists of a high-resolution ion microscope for ground state and Rydberg atoms with magnifications up to 1000 and a spatial resolution in the 100nm regime. The blockade effect becomes evident in the spatial $g^{(2)}$ correlation function between individual detection events. We show that the strength of the blockade effect can be sensitively adjusted by small changes in the electric field strength. This opens up new perspectives for quantum simulation techniques.

Q 8.3 Mon 11:15 K 2.013

Free-Space Quantum Electrodynamics with Rydberg Superatoms — •Simon Ball[1], Christoph Tresp[1], Nina Stiesdal[1], Asaf Paris-Manodki[2], Jan Kumlin[3], Philipp Lunt[1], Christoph Braun[1], Hans Peter Büchler[3], and Sebastian Hofferberth[1] — [1]Department of Physics, Chemistry and Pharmacy, University of Southern Denmark, 5230 Odense, Denmark — [2]Instituto de Física, Universidad Nacional Autónoma de México, Mexico City 04510 Mexico — [3]Institut für Theoretische Physik III and Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, Germany

Achieving significant coupling between single photon and single atom in free space is challenging. Finding ways to increase the coupling strength has brought about cavity, circuit and more recently waveguide QED, where the electromagnetic wave is either trapped or transversely confined. We present the coherent interaction of a single Rydberg superatom interacting with a propagating, single mode, few-photon light field. Due to the collective nature of the excitation, the superatom inherits the light field's phase-relation and emits only in forward direction.[1] This property can be utilized to implement a dissipative spin chain, where the interaction between the individual spins is consecutively mediated by unidirectional travelling individual photons.

[1] A. Paris-Mandoki, C. Braun, J. Kumlin, C. Tresp, I. Mirgorodskiy, F. Christaller, H. P. Büchler, and S. Hofferberth, Phys. Rev. X 7, 41010 (2017).

Q 8.4 Mon 11:30 K 2.013

On-demand single-photon source based on thermal rubidium — •Fabian Ripka, Florian Christaller, Hao Zhang, Harald Kübler, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

Photonic quantum devices based on atomic vapors at room temperature combine the advantages of atomic vapors being intrinsically reproducable as well as semiconductor-based concepts being scalable and integrable. One key device in the field of quantum information are on-demand single-photon sources. A promising candidate for realization relies on the combination of two effects in atomic ensembles, namely four-wave mixing (FWM) and the Rydberg blockade effect, comparable to similar realizations using cold atoms [1].

Coherent dynamics to Rydberg states [2] and sufficient Rydberg interaction strengths [3] have already been demonstrated in thermal vapors. Additionally, time-resolved probing of collective Rydberg excitation has been performed [4], revealing a lifetime long enough for effective Rydberg-Rydberg interactions.

In the current state of the experiment, the Rydberg blockade sphere is larger than the excitation volume. We report on effects on the light statistics of the emitted photons we observed in the experiment.

[1] Y. O. Dudin et al., Science 336, 6083 (2012)
[2] Huber et al., PRL 107, 243001 (2011)
[3] Baluktsian et al., PRL 110, 123001 (2013)
[4] Ripka et al., Phys. Rev. A, 053429 (2016)

Q 8.5 Mon 11:45 K 2.013

Imaging nonlocal photon interactions in a cold Rydberg gas — •Annika Tebben[1], Valentin Walther[3], Renato Ferracini Alves[1], Yongchang Zhang[3], Andre Salzinger[1], Clement Hainaut[1], Nithiwadee Thaicharoen[1], Gerhard Zürn[1], Thomas Pohl[3], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 226, 69129 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China — [3]Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK 8000 Aarhus C, Denmark

Rydberg interactions modify the transmission of a light field through a cold atomic gas under conditions of electromagnetically induced transparency (EIT).

In this work, we develop a theory for the nonlinear, nonlocal optical response in a such a medium, without employing the adiabatic elimination of the intermediate state. We find an enhancement of this response in the vicinity of the single-photon resonance due to resonant Rydberg dressing of the atoms. Simulations show that this enhancement can be observed experimentally in the transmission of the EIT probe beam.

Q 8.6 Mon 12:00 K 2.013

Emergent universal dynamics for an atomic cloud coupled to an optical waveguide — •Jan Kumlin[1], Sebastian Hofferberth[2], and Hans Peter Büchler[1] — [1]Institut für Theoretische Physik III and Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, Germany — [2]Department of Physics, Chemistry and Pharmacy, University of Southern Denmark, 5230 Odense, Denmark

Motivated by recent experiments on strong coupling of a cloud of Rydberg atoms coupled to a propagating light field [1], we study the effect of interaction-induced dephasing in an atomic cloud of atoms coupled to an optical one-dimensional waveguide. The system's dynamics can then be described by dissipative terms characterising the collective emission of photons and coherent interaction due to the virtual exchange of photons. We show that the coherent exchange interaction gives rise to universal dynamics with coherent oscillations and dephasing on a time scale that grows with the number of atoms in the cloud. Further, we discuss a possible experimental setup to decouple coherent and dissipative dynamics in order to observe the universal dynamics.

[1] A. Paris-Mandoki, C. Braun, J. Kumlin, C. Tresp, I. Mirgorodskiy, F. Christaller, H. P. Büchler, and S. Hofferberth, Phys. Rev. X 7, 41010 (2017)

Q 9: Cold atoms II - interactions (joint session A/Q)

Time: Monday 10:30–12:00 Location: K 2.019

Q 9.1 Mon 10:30 K 2.019

Dimensional Crossover for the Beyond-Mean-Field Corrections in the Weakly Interacting Bose Gas — •Tobias Ilg, Jan Kumlin, and Hans Peter Büchler — Institute for Theoretical Physics III, University of Stuttgart, 70569 Stuttgart, Germany

We investigate the beyond-mean-field corrections in a confined weakly interacting Bose gas at zero temperature. The system is elongated along one direction and tightly confined along the transverse directions. The confined gas can exhibit three-dimensional as well as quasi-one-dimensional behavior. We use the field-theoretic approach of Hugenholtz and Pines to include beyond-mean-field corrections. The field-theoretic treatment allows us to connect the three-dimensional regime to the quasi-one-dimensional regime and to describe a dimensional crossover of the system. We show that the inclusion of the beyond-mean-field terms leads to a correction of the coupling constant in the quasi-one-dimensional regime due to the presence of the confinement. Thus, the confinement-induced shift of the ground state energy appears naturally in our approach.

Q 9.2 Mon 10:45 K 2.019

Time-dependent variational Monte Carlo method for interacting Bosons in continuous space — •Markus Holzmann — LPMMC, UMR 5493 of CNRS, Université Grenoble Alpes, F-38042 Grenoble, France

I will describe time-dependent Variational Monte Carlo method for continuous-space Bose systems based on a systematic truncation of the many-body wave function [1]. We have benchmarked the method by studing the Lieb-Liniger model of one dimensional Bosons interacting by a delta potential. We have calculated static ground state properties, as well as the unitary dynamics after a sudden quench in the interaction strength and compared to Bethe ansatz results wherever available.

[1] G. Carleo, L. Cevolani, L. Sanchez-Palencia, and M. Holzmann, Phys. Rev. X 7, 031026 (2017).

Q 9.3 Mon 11:00 K 2.019

Commensurate-Incommensurate Transition in Optical Cavities — •Andreas Alexander Buchheit[1], Haggai Landa[2], Cecilia Cormick[3], Thomas Fogarty[4], Eugene Demler[5], and Giovanna Morigi[1] — [1]Saarland University, 66123 Saarbrücken — [2]IPhT, CEA Saclay, France — [3]IFEG, CONICET and Universidad Nacional de Cordoba — [4]Okinawa Institute of Science and Technology, Japan — [5]Department of Physics, Harvard University, Cambridge, MA 02138, USA

We theoretically analyse the equilibrium configuration of an ion chain which interacts with the optical lattice of a cavity mode. We assume the lattice periodicity is almost commensurate with the interparticle distance of the ions and determine the resulting configuration as a function of their ratio. In the limit of small cooperativity, when cavity backaction is negligible, we show that this system simulates the commensurate-incommensurate phase transition. We derive a field theory for the kinks that are created in the incommensurate phase and determine the effects of the Coulomb repulsion on the phase diagram. When instead the cavity strongly couples to the ions motion we show that the commensurate-incommensurate transition becomes of first order and is associated with bistable behaviour of the cavity field. We characterize the kinks and their interactions and determine the properties of the light at the cavity output across the phase transition.

Q 9.4 Mon 11:15 K 2.019

Observation of the Higgs mode in a strongly interacting fermionic superfluid — •Martin Link[1], Alexandra Behrle[1], Timothy Harrison[1], Johannes Kombe[2], Kuiyi Gao[1], Jean-Sebastien Bernier[2], Corinna Kollath[2], and Michael Köhl[1] — [1]Physikalisches Institut, University of Bonn, Wegelerstrasse 8, 53115 Bonn, Germany — [2]HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

Higgs and Goldstone modes are possible collective modes of an order parameter upon spontaneously breaking a continuous symmetry. Whereas the low-energy Goldstone (phase) mode is always stable, additional symmetries are required to prevent the Higgs (amplitude) mode from rapidly decaying into low-energy excitations. In the realm of condensed-matter physics, particle-hole symmetry can play this role and a Higgs mode has been observed in weakly-interacting superconductors. However, whether the Higgs mode is also stable for strongly-correlated superconductors in which particle-hole symmetry is not precisely fulfilled or whether this mode becomes overdamped has been subject of numerous discussions. Here, we observe the Higgs mode in a strongly-interacting superfluid Fermi gas. By inducing a periodic modulation of the amplitude of the superconducting order parameter Δ, we observe an excitation resonance at frequency $2\Delta/h$. For strong coupling, the peak width broadens and eventually the mode disappears when the Cooper pairs turn into tightly bound dimers signalling the eventual instability of the Higgs mode.

Q 9.5 Mon 11:30 K 2.019

Breaking of SU(4) symmetry and interplay between strongly correlated phases in the Hubbard model — •Agnieszka Cichy[1,2] and Andrii Sotnikov[3,4] — [1]Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614 Poznan, Poland — [2]Umultowska 85 — [3]Institute of Solid State Physics, TU Wien, Wiedner Hauptstr. 8, 1040 Wien, Austria — [4]Akhiezer Institute for Theoretical Physics, NSC KIPT, 61108 Kharkiv, Ukraine

We study the thermodynamic properties of four-component fermionic mixtures described by the Hubbard model using the dynamical mean-field-theory approach. Special attention is given to the system with SU(4)-symmetric interactions at half filling, where we analyze equilibrium many-body phases and their coexistence regions at nonzero temperature for the case of simple cubic lattice geometry. We also determine the evolution of observables in low-temperature phases while lowering the symmetry of the Hamiltonian towards the two-band Hubbard model. This is achieved by varying interflavor interactions or by introducing the spin-flip term (Hund's coupling). We observe a strong effect of suppression of ferromagnetic order in comparison with previous studies that were usually performed by restricting to density-density interactions. By calculating the entropy for different symmetries of the model, we determine the optimal regimes for approaching the studied phases in experiments with ultracold alkali and alkaline-earth-like atoms in optical lattices.

Q 9.6 Mon 11:45 K 2.019

Polaron physics with ultracold atoms and beyond — •Richard Schmidt — Department of Physics, Harvard University, Cambridge, MA 02138, USA — ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA — Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

When an impurity interacts with an environment, it changes its properties and forms a polaron. Depending on the character of the environment, various types of polarons are created. In this talk, I will review recent progress on studying the physics of polarons in cold atoms [1], and discuss related phenomena in semiconductors and the study of rotating molecules in Helium droplets [2]. Then I will show that Rydberg excitations coupled to BECs are a new, exciting playground for the study of polaronic physics. Here the impurity-bath interaction is mediated by the Rydberg electron. This gives rise to a new polaronic dressing mechanisms, where molecules of gigantic size dress the Rydberg impurity. We develop a functional determinant approach [3] which incorporates atomic and many-body theory. Using this approach we predict the appearance of a superpolaronic state, recently observed in experiments [4,5].

References: [1] R. Schmidt, et al, arXiv:1702.08587 (2017). [2] R. Schmidt, and M. Lemeshko, Phys. Rev. Lett. 114, 203001 (2015); [3] R. Schmidt, H. Sadeghpour, and E. Demler, Phys. Rev. Lett. 116, 105302 (2016). [4] F. Camargo et al., arXiv:1706.03717 (2017). [5] R. Schmidt et al., arXiv:1709.01838 (2017).

Q 10: Quantum Gases (Bosons) I

Time: Monday 10:30–12:30 Location: K 2.020

Q 10.1 Mon 10:30 K 2.020

Microscopy of many-body localization in one dimension — •Julian Léonard, Alexander Lukin, Matthew Rispoli, Robert Schittko, Eric Tai, and Markus Greiner — Harvard University, Cambridge, MA, USA

Many-body localization (MBL) challenges our understanding of thermalization in quantum systems. While non-equilibrium systems usually relax and approach thermal equilibrium, MBL systems remain in a state far from equilibrium.

We study this behaviour in a Bose-Hubbard chain that is subject to a controlled disorder potential. We start with a system at unity filling and prepare it in an out-of-equilibrium state by quenching the tunneling rate from zero a to a finite value. By performing site-resolved full counting statistics, we are able to locally measure the atom number distribution, determine the degree of thermalization, and extract the on-site entropy. We observe a breakdown of thermalization at high disorders, locally suppressed thermalization at the boundaries and map out the MBL transition.

Q 10.2 Mon 10:45 K 2.020

Quantum thermalization in isolated ultracold gases — •Marvin Lenk[1], Anna Posazhennikova[2], Tim Lappe[1], and Johann Kroha[1] — [1]Physikalisches Institut, Universität Bonn, Germany — [2]Department of Physics, Royal Holloway University of London, UK

Quantum thermalization, i.e., how an isolated quantum system with unitary time evolution can ever reach thermal equilibrium behavior, is a long-standing problem of quantum statistics. It has moved in the focus of attention due to realizations in ultracold gas systems. The eigenstate thermalization hypothesis (ETH) poses that, under certain restrictive conditions, a microcanonical average is indistinguishable from the expectation value w.r.t. a typical eigenstate. By contrast, thermal behavior is reached quite generally in a non-integrable quantum many-body system alone due to the vast size of the Hilbert space dimension D. In any realistic experiment, only a small subset of the quantum numbers defining a pure state can be measured, if D is sufficiently large. The Hilbert space spanned by the undetermined quantum numbers is traced over and, thus, forms a grand canonical bath [Ann. Phys. 1700124 (2017)]. We show that this mechanism is valid for a generic system of N interacting bosons in M single-particle levels by computing numerically exactly the time evolution of the reduced densitiy matrix, the entanglement entropy as well as expectation values and fluctuations for the observed subsystem. The thermalizing quantities are, thus, defined by the measurement itself and not restricted to local observables. For $N \approx 25$ and $M \approx 5$, D is already large enough for thermalization to occur. We also analyze the validity of ETH.

Q 10.3 Mon 11:00 K 2.020

Observation of universal dynamics in an isolated quantum system — •Maximilian Prüfer[1], Philipp Kunkel[1], Christian-Marcel Schmied[1], Daniel Linnemann[1], Stefan Lannig[1], Helmut Strobel[1], Jürgen Berges[2], Thomas Gasenzer[1], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg

After a quench a non-integrable many-particle system will eventually relax to its thermal state. However, on the route to thermalisation universal dynamics characterised by temporal rescaling of spatial correlation functions may be encountered, a phenomenon known as a non-thermal fixed point. We access and study this regime both experimentally and theoretically for a Bose-Einstein condensate of ^{87}Rb in the $F = 1$ hyperfine manifold with ferromagnetic interactions. We prepare our system in the polar phase and quench into the easy-plane ferromagnetic phase. After a build-up of excitations in the transversal spin we observe self-similar evolution, which is due to the non-linear redistribution of excitations among different momenta. We determine the emerging scaling form for the structure factor of the transversal spin and extract the set of corresponding scaling exponents. Our results give access to universal properties of the transient dynamics towards thermal equilibrium.

Q 10.4 Mon 11:15 K 2.020

Damping of BEC Josephson oscillations by dynamical fluctuation excitation — •Tim Lappe[1], Anna Posazhennikova[2], and Johann Kroha[1] — [1]Physikalisches Institut and Bethe Center for Theoretical Physics, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Department of Physics, Royal Holloway, University of London, Egham, Surrey TW20 0EX, UK

The nonequilibrium dynamics of Bose-Josephson junctions can be investigated with Bose-Einstein condensates (BEC) of cold atoms in double-well traps. These systems are perfectly isolated, yet the experiments manifest an intriguing divergence: While some exhibit dissipation-free Josephson oscillations, others show strong damping. Some of us have demonstrated before how inelastic collisions of incoherent excitations can lead to damping and eventual thermalization [PRL 116, 225304 (2016)]. Here we scrutinize the generation of such excitations in realistic traps and their effect on damping. This cannot be achieved on the usual Gross-Pitaevskii (GP) level. Using a Keldysh path-integral formalism, we develop a time-dependent, multimode description beyond the GP equation, including quadratic fluctuations. We find an excess of fluctuations when their renormalized excitation energy, $\tilde{\varepsilon}$, is near the renormalized Josephson frequency, $\tilde{\omega}_J$. Both $\tilde{\varepsilon}$ and $\tilde{\omega}_J$ are strongly renormalized by interactions. Calculating the system parameters and coupling constants quantitatively, we show that these renormalizations can explain the apparently contradictory damping behavior of two well-known experiments. This sheds light on the unresolved origin of damping observed in these isolated systems.

Q 10.5 Mon 11:30 K 2.020

Spin dynamics of individual neutral impurities coupled to a Bose-Einstein condensate — •Felix Schmidt[1], Daniel Mayer[1], Daniel Adam[1], Quentin Bouton[1], Tobias Lausch[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

Individual spins immersed into a superfluid form a paradigm of quantum physics. It lies at the heart of many models exploiting the quantum nature of individual spin to understand quantum phenomena or to open novel routes to local probing and engineering of quantum many-body systems.

We report on the controlled immersion of individual localized neutral Caesium (Cs) atoms having total spin $F = 3$ into a Rubidium Bose-Einstein condensate (BEC) with total spin $F = 1$. We observe inelastic spin exchange as well as coherent dynamics of the Cs impurity's quasispins interacting with the BEC with high position and time resolution. Our work paves the way for local quantum probing of superfluids, and thus might shed light on the local state of nonequilibrium or correlated quantum many-body systems.

Q 10.6 Mon 11:45 K 2.020

Quantum Chaos of Cold Atoms in Optical Lattices: A Trajectory-Based Analysis of Out-Of-Time-Ordered Correlators in Many-Body Space — •Josef Rammensee, Juan Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

To address the question of how to measure many-body quantum chaos, i.e. the influence of classical chaos underlying a quantum many-particle system, so-called out-of-time-ordered correlators $\langle[\hat{V},\hat{W}(t)]^{\dagger}[\hat{V},\hat{W}(t)]\rangle$ have been identified to be highly suitable tools[1]. Contrary to already known indicators, their unusual time ordering of the operators is able to directly capture the hyperbolic nature of the classical counterpart, as one expects an exponential increase at short times with a rate related to classical Lyapunov exponents. Arguments based on a naive quantum-classical correspondence motivate this expectation. Numerical studies further indicate, without quantitative explanation, a later saturation after the time scale for the classical-to-quantum-crossover, known as Ehrenfest or scrambling time. Here we provide insight into the physical origin of the exponential growth and the saturation by using semiclassical methods based on the Van-Vleck-propagator for Bose-Hubbard systems[2]. We show that the notion of interfering classical mean-field trajectories is well suited to provide a quantitative picture for interacting bosonic systems. We explicitly discuss the emergence of the Lyapunov exponent and the relevant time scales.

[1] J. Maldacena *et al.*, J. High Energ. Phys. (2016) 2016:106.
[2] T. Engl, J. Dujardin, A. Argüelles *et al.*, PRL **112**, 140403 (2014)

Q 10.7 Mon 12:00 K 2.020

Off-resonant many-body quantum carpets in strongly tilted optical lattices — Manuel H. Muñoz-Arias, •Javier Madroñero, and Carlos A. Parra-Murillo — Physics Department, Universidad del Valle, Cali, Colombia

A unit filling Bose-Hubbard Hamiltonian embedded in a strong Stark field is studied in the off-resonant regime inhibiting single- and many-particle first-order tunnelling resonances. We investigate the occurrence of coherent dipole wavelike propagation along an optical lattice by means of an effective Hamiltonian accounting for second-order tunnelling processes. It is shown that dipole wave function evolution in the short-time limit is ballistic and that finite-size effects induce dynamical self-interference patterns known as quantum carpets.

Q 10.8 Mon 12:15 K 2.020

Reconstructing quantum states of cold atomic quantum simulators from non-equilibrium dynamics — •Marek Gluza[1], Thomas Schweigler[2], Bernhard Rauer[2], Christian Krumnow[1], Joerg Schmiedmayer[2], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria

Systems of ultra-cold atoms on atom chips provide an architecture to probe aspects of out-of-equilibrium quantum many-body physics including equilibration, thermalization and pre-thermalization. We present a novel tomographic reconstruction method for these quantum simulators allowing to access the expectation value of quadrature operators which are inaccessible from direct measurements but capture crucial characteristics of the elementary excitations of cold atomic systems. Specifically, we use interferometric data of non-equilibrium phase fluctuations to reconstruct the covariance matrix – including density fluctuations – of eigenmodes of the corresponding mean-field models. Experimentally, we observe quench dynamics in the non-interacting regime of particles in harmonic or box potentials. Formally, we use that one can efficiently keep track of the evolution and employ signal processing and semi-definite programming to perform a reliable reconstruction of covariance matrices. This method opens a new window into the study of dynamical quantum simulators – an insight that we exploit and discuss at the hand of several examples, including Gaussifying quantum many-body dynamics.

Q 11: Cold atoms III - optical lattices (joint session A/Q)

Time: Monday 14:00–15:30 Location: K 0.011

Q 11.1 Mon 14:00 K 0.011

Quantum simulation of lattice gauge theories using Wilson fermions — •Torsten V. Zache[1], Philipp Hauke[1,2], Fred Jendrzejewski[2], Florian Hebenstreit[3], Markus Oberthaler[2], and Jürgen Berges[1] — [1]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg — [2]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg — [3]Institute for Theoretical Physics, Sidlerstr. 5, CH-3012 Bern

Gauge theories play an essential role in the formulation of microscopic quantum field theories, e.g. QED or QCD. Their analytical treatment is typically limited to the perturbative regime and numerical simulations are strongly hampered by the sign problem. Recently, quantum simulators based on cold atomic gases in optical lattices have been proposed to circumvent these issues. Most proposals rely on the lattice regularization of gauge theories (LGT) via staggered fermions. Since the regularization is not unique, we propose to exploit this freedom to simplify the implementation of LGTs. We find that the choice of Wilson fermions reduces the complexity of the gauge interactions in one spatial dimension to a minimum and use this result to devise an optimized implementation of QED using a mixture of bosons and fermions in a tilted optical potential. We further perform benchmarking real-time lattice simulations with realistic experimental parameter sets, which indicate that the non-perturbative nature of electron-positron pair production due to the Schwinger mechanism can be resolved even quantitatively. We conclude that the quantum simulation of QED in the continuum limit is possible with state-of-the art technology.

Q 11.2 Mon 14:15 K 0.011

Chimera patterns in conservative systems and ultracold atoms with mediated nonlocal hopping — •Hon-Wai Lau[1,2,3], Jörn Davidsen[3], and Christoph Simon[2] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, D-01187 Dresden — [2]Institute for Quantum Science and Technology and Department of Physics and Astronomy, University of Calgary, Calgary, Alberta, Canada T2N 1N4 — [3]Complexity Science Group, Department of Physics and Astronomy, University of Calgary, Canada T2N 1N4

Chimera patterns, characterized by coexisting regions of phase coherence and incoherence, have been experimentally demonstrated in mechanical, chemical, electronic, and opto-electronic systems. The patterns have so far been studied in non-conservative systems with dissipation. Here, we show that the formation of chimera patterns can also be observed in conservative Hamiltonian systems with nonlocal hopping in which both energy and particle number are conserved. We further show the physical mechanism and the implementation in ultracold atomic systems: Nonlocal spatial hopping over up to tens of lattice sites with independently tunable hopping strength and on-site nonlinearity can be implemented in a two-component Bose-Einstein condensate with a spin-dependent optical lattice, where the untrapped component serves as the matter-wave mediating field. The present work highlights the connections between chimera patterns, nonlinear dynamics, condensed matter, and ultracold atoms.

Q 11.3 Mon 14:30 K 0.011

Interorbital spin exchange in a state-dependent optical lattice — •Luis Riegger[1,2], Nelson Darkwah Oppong[1,2], Moritz Höfer[1,2], Diogo Rio Fernandes[1,2], Immanuel Bloch[1,2], and Simon Fölling[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Ludwig-Maximilians-Universität, München

We report on the observation of tunable interorbital spin exchange in the presence of a state-dependent optical lattice for the ground state and metastable clock state of fermionic ytterbium-173. The optical lattice potential is independent of the nuclear spin and preserves the SU(N)-symmetry of the interactions, typical for alkaline-earth-like atoms. In the state-dependent lattice, excited-state and ground-state atoms act as localized and mobile magnetic moments. The large difference in the interaction strength for spin-triplet and singlet states leads to spin-exchanging dynamics between the magnetic moments mediated by exchange processes similar to those in the Anderson impurity model. Moreover, we find that the external confinement can be used to resonantly tune the exchange dynamics. This makes our system a promising platform for the study of Kondo- and Kondo-lattice-type physics.

Q 11.4 Mon 14:45 K 0.011

Observation of Feshbach resonances between alkali and closed-shell atoms — •Vincent Barbé[1], Alessio Ciamei[1], Lukas Reichsöllner[1], Benjamin Pasquiou[1], Florian Schreck[1], Piotr Zuchowski[2], and Jeremy Hutson[3] — [1]University of Amsterdam, The Netherlands — [2]Nicolaus Copernicus University, Poland — [3]Durham University, United Kingdom

Magnetic Feshbach resonances are widely used to tune interactions of ultracold atoms or to magneto-associate pairs of atoms into diatomic molecules. Such resonances have been observed and used extensively for pairs of open-shell atoms, but were never detected for pairs of alkali and closed-shell atoms. Here we demonstrate experimentally the existence of such resonances in mixtures of ^{87}Sr or ^{88}Sr with ^{87}Rb [1]. Two of the coupling mechanisms involved in these Feshbach resonances were theoretically investigated in previous works [2], and in addition we discover a new form of anisotropic coupling between rotating molecular states and s-wave scattering states. This opens a route towards the magneto-association of Rb and Sr into open-shell, strongly polar molecules in an optical lattice.

[1] V. Barbé *et al.*, arXiv:1710.03093 (2017).
[2] P. Żuchowski *et al.*, Phys. Rev. Lett. 105, 153201 (2010).

Q 11.5 Mon 15:00 K 0.011

Robust features of Bose-Hubbard eigenstates dressed by a cavity — •Jonas Mielke, Laurent de Forges de Parny, and Andreas Buchleitner — Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany

The coherent dressing by a cavity field allows to induce long-range interactions between otherwise only locally interacting bosons in optical lattices [1]. Most studies did so far address ground state properties like long-range phase coherence and spatial ordering [2,3], while also the excitation spectrum of these systems can be expected to exhibit nontrivial structural features. We present a complete map of the system states' characteristic structural features, across the entire excitation spectrum, which generalizes standard ground state phase diagrams, for minimal system sizes. We discuss the physical mechanisms which define the smooth demarcation lines between different structural properties in parameter space, and analyse relevant scaling properties with the system size.

[1] C. Maschler, I. Mekhov, and H. Ritsch, Eur. Phys. J. D,46, 545-560 (2008);
[2] R. Landig, L. Hruby, N. Dogra, M. Landini, R. Mottl, T. Donner, and T. Esslinger, Nature 532, 476 (2016);
[3] T. Flottat, L. de Forges de Parny, F. Hébert, V.G. Rousseau, and G.G. Batrouni, Phys. Rev. B 95, 144501 (2017).

Q 11.6 Mon 15:15 K 0.011

Metastability and avalanche dynamics in strongly-correlated gases with long-range interactions — •Nishant Dogra, Lorenz Hruby, Manuele Landini, Katrin Kröger, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

We experimentally study the stability of a bosonic Mott-insulator against the formation of a density wave induced by long-range interactions. The Mott-insulator is created in a quantum degenerate gas of 87-Rubidium atoms, trapped in a three-dimensional optical lattice. The gas is located inside and globally coupled to an optical cavity. This causes interactions of global range, mediated by photons dispersively scattered between a transverse lattice and the cavity. The scattering comes with an atomic density modulation, which is measured by the photon flux leaking from the cavity. We initialize the system in a Mott-insulating state and then quench the global coupling strength. We observe that the system falls into either of two distinct final states. One is characterized by low photon flux, signaling a Mott insulator, and the other is characterized by high photon flux, which we associate with a density wave. Ramping the global coupling slowly, we observe a hysteresis loop between the two states. From the increasing photon flux monitored during the switching process, we find that several thousand atoms tunnel to a neighboring site on the time scale of the single particle dynamics which can be understood as an avalanche tunnelling process in the Mott-insulating region.

Q 12: Quantum Optics II

Time: Monday 14:00–16:00 Location: K 0.016

Q 12.1 Mon 14:00 K 0.016

A free-electron laser oscillator in the quantum regime — •Peter Kling[1,2], Enno Giese[3,1], Roland Sauerbrey[2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQ$^{\mathrm{ST}}$, Universität Ulm, D-89069 Ulm — [2]Helmholtz-Zentrum Dresden-Rossendorf e.V., D-01314 Dresden — [3]University of Ottawa, Ottawa, Ontario K1N 6N5, Canada

Decreasing the wavelength of a free-electron laser (FEL) increases the quantum mechanical recoil an electron experiences, when it scatters with the light fields, and ultimately leads to the emergence of quantum effects. If the recoil dominantes the dynamics, we speak of the quantum regime of the FEL [1]. In this limit, the electron populates only two resonant momentum levels [2,3].

We present here the theory of a low-gain FEL oscillator in the quantum regime and derive properties such as the gain and the steady-state photon statistics. Moreover, we compare this device with (i) the micromaser and (ii) the classical FEL.

[1] R. Bonifacio, N. Piovella, and G. R. M. Robb, Fortschr. Phys. **57**, 1041 (2009).
[2] P. Kling *et al.*, New J. Phys. **17**, 123019 (2015).
[3] P. Kling *et al.*, Appl. Phys. B **123**, 9 (2017).

Q 12.2 Mon 14:15 K 0.016

Time-Resolved Photon Statistics Measurements at Lasing Threshold with Homodyne Detection — •Carolin Lüders, Johannes Thewes, and Marc Assmann — Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany

For laser science and application, understanding the temporal dynamics of the lasing transition is crucial. An indicator for characterizing the light state during this process is the second-order correlation function $g^{(2)}(\tau = 0, t)$, which distinguishes between Poissonian or thermal photon statistics. However, recording it over longer timescales while maintaining a high time resolution is needed for a detailed analysis. By employing homodyne detection, where a pulsed Local Oscillator field provides temporal selectivity, we observed $g^{(2)}$ of a diode laser with microsecond time resolution. Thus, we were able to investigate its switching between coherent and thermal mode on various time scales. While our findings provide insight in the dynamics of the lasing transition, our method may also be applied to investigate light from samples such as polariton microcavities or to test the fidelity of memories for optical quantum information.

Q 12.3 Mon 14:30 K 0.016

Quantum-limited Coherent Combination of Optical Signals — •Sourav Chatterjee[1,2,3], Christian R. Müller[1,2], Florian Sedlmeir[1,2], Christoph Marquardt[1,2,3], and Gerd Leuchs[1,2,3] — [1]MPI for the Science of Light, Erlangen, Germany — [2]Department of Physics, FAU, Erlangen, Germany — [3]School in Advanced Optical Technologies, Erlangen, Germany

Extremely powerful lasers are needed for various applications in science and industry. State-of-the-art technology only offers quantum-noise-limited lasers in the power range of a few watts. Thermal mode instabilities (TMI) cause high quality fibre laser beams to become unstable above a certain threshold power [1]. This limits the precision of quantum-limited metrology as well as the efficiency of coherent parametric processes.

Coherent combination enables the scaling of fibre laser power beyond the TMI threshold. In this technique, multiple weaker quantum-noise-limited beams, split from a seed laser, are individually amplified with identical fibre amplifiers operating below TMI threshold and then recombined by a series of beam-splitters to generate a high power beam

[2]. However, the quality of the output beam depends crucially on the interference after the beam-splitter series. In our experiment, we demonstrate interferometric locking schemes utilizing quantum-limited phase measurements along with fast feedback electronics to investigate fundamental boundaries and quantum limits of coherent combination.

[1] T. Eidam et al., Opt. Express 19 (2011).
[2] H. Tünnermann et al., Opt. Express 19 (2011).

Q 12.4 Mon 14:45 K 0.016

quantum backscatter communication — •Roberto Di Candia — Freie Universitat, Berlin, Germany

Quantum illumination is a revolutionary photonic quantum sensing technology that improves the hypothesis testing performance in noisy and lossy environments. On the other hand, backscatter communication is a long-standing paradigm making use of amplitude and phase modulation together with radar technology to allow data transmission between devices. In this talk, we show how quantum illumination enhances the performance of backscatter communication protocols. We study a narrowband system, in which the symbol duration is long enough that the photodetector receiver is able to receive a sufficiently large number of photons before making any decision. We rigorously derive the signal-to-noise ratio gain in the error probability exponent for the cases of Gaussian and non-Gaussian states as input. We also characterize the quantum radar cross-section of a simple flat dipole antenna and propose a simple model of Rician fading in the quantum setting. These results extend the usefulness of quantum illumination performance beyond the quantum radar, which is supposed to be long-range and, therefore, challenging to build.

Q 12.5 Mon 15:00 K 0.016

Optimization of photovoltaic upconversion by tailoring the photonic density of states — •Fabian Spallek, Andreas Buchleitner, and Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Upconversion materials, which convert two low-energy photons into one photon with higher energy, combined with photonic structures, open promising possibilities to improve the efficiency of silicon solar cells by utilizing the full range rather than only a fraction of the solar spectrum [1]. Quantum yield and the luminescence enhancement, which quantify the overall efficiency of the embedded upconverter material, are determined by the interplay of energy transfer processes, local irradiance and local density of (photonic) states - all of which can be influenced by photonic dielectric nanostructures. We derive the local density of states from macroscopic QED, for arbitrary finite multi-layered dielectric structures. This allows us to optimize the structure, such as to enhance desired, or to suppress unwanted spontaneous emission processes from distinct excited energy levels of the upconverter material. In combination with previous results on the optimization of the local irradiance in multi-layered structures [2], we compare our predictions for the achievable luminescence and upconversion quantum yield to thus far experimentally implemented [1] Bragg structures.

[1] C. L. M. Hofmann et al., Opt. Express 24, 14895 (2016)
[2] F. Spallek et al., J. Phys. B: At. Mol. Opt. Phys. 50, 214005 (2017)

Q 12.6 Mon 15:15 K 0.016

The 1 m prototype for the 'Any Light particle Search' experiment — •Kanioar Karan, Dennis Schmelzer, Li-Wei Wei, and Benno Willke — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstraße 38, 30167 Hannover

Extensions of the Standard Model of particle physics predict a variety of new particles, among them so-called WISPs, or very Weakly Interacting Sub-eV Particles. The most famous WISP candidate is the axion.

The ALPS collaboration is setting up a light shining through a wall experiment (LSW) for production and detection of WISPs. This experiment is based on the simple idea that a high power laser field that traveled through a static magnetic field can partly oscillate into an axion filed. The axion field then cross an opaque wall to a second static magnetic field and re-oscillate into an electromagnetic field. On both sides of the wall optical cavities are used to increase the laser field for the WISPs production and the likelihood for the re-oscillation of the WISPs into electromagnetic fields.

A key challenge in the experiment is to achieve a spatial overlap of 95% of the two optical cavities. Therefore, the parallelism of the cavity mirrors has to be $\leq 5\mu$rad. With the 1m prototype table-top experiment the ALPS collaboration will show with a breadboard concept how to achieve a parallelism of 5μrad and the required spatial overlap of 95%. We will report on the status of this 1m-prototype experiment.

Q 12.7 Mon 15:30 K 0.016

Experimental setup for quantum logic inspired cooling and detection of single (anti-)protons — •Teresa Meiners[1], Johannes Mielke[1], Malte Niemann[1], Juan M. Cornejo[1], Anna-Greta Paschke[1,2], Matthias Borchert[1], Jonathan Morgner[1], Amado Bautista-Salvador[2,1], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch Technische Bundesanstalt, Braunschweig — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN

The goal of the QLEDS (Quantum Logic Enabled Test of Discrete Symmetries) experiment is to develop quantum logic inspired techniques for the comparison of the magnetic moments of the proton and the antiproton to test CPT invariance. Therefore, the spin state of the proton in a Penning trap has to be determined. Following a proposal by Heinzen and Wineland [1], sympathetic cooling, state preparation and spin state readout could be done using a co-trapped atomic ion. These ideas could be implemented within the BASE collaboration [2] to obtain significantly lower temperatures and faster cycle times.

Here, we report on the current status of the project. We present the experimental apparatus that consists of several stacked cylindrical Penning traps. This configuration allows for (sympathetic) cooling, transport, and motional coupling of two Be^+ ions.

[1] Heinzen and Wineland, PRA **42**, 2977 (1990)
[2] C. Smorra *et al.*, Eur. Phys. J. Special Topics **224**, 3055-3108 (2015)

Q 12.8 Mon 15:45 K 0.016

Spectral properties of ultrabroadband squeezed pulses of quantum light — •Thiago Lucena de M. Guedes, Matthias Kizmann, Guido Burkard, and Andrey S. Moskalenko — University of Konstanz, Konstanz, Germany

In recent years, a series of works [1,2,3] provided a deeper understanding on how to sample and squeeze the vacuum fluctuations of the electric field at a femtosecond time scale. Following the respective works, the squeezing operator for an ultrabroadband (continuous) multimode squeezed vacuum state generated in a thin nonlinear crystal was derived. The squeezing is found to depend on the shape and duration of the pump pulse that enters one of the ports of the generating crystal. The photon number density distribution in frequency for such squeezed states can be calculated perturbatively and shows to a good accuracy an exponential decaying behavior for most of the pump field shapes. We compare the corresponding spectra with the spectrum of the Unruh-Davies radiation [4,5], which would be seen by a detector at rest in a highly-accelerated non-inertial reference frame. We analyze the temporal behavior of the normal-ordered variance of the electric-field operator. On the subcyle time scale there are pronounced differences to the conventional harmonic dependence of the variance of a single-mode squeezed state on the phase delay.

[1] C. Riek et al., Science 350, 420 (2015). [2] A.S. Moskalenko et al., Phys. Rev. Lett. 115, 263601 (2015). [3] C. Riek et al., Nature 541, 376 (2017). [4] W. G. Unruh, Phys. Rev. D 14, 870 (1976). [5] P. C. W. Davies, J. Phys. A 8, 609 (1975).

Q 13: Laser Development and Applications (joint session Q/A)

Time: Monday 14:00–15:45 Location: K 0.023

Q 13.1 Mon 14:00 K 0.023

Pump-power scaling of a diode-pumped Alexandrite laser — •Martin Walochnik[1], Hans Huber[1], Bernd Jungbluth[2], Alexander Munk[2], Michael Strotkamp[2], Dieter Hoffmann[2], and Reinhart Poprawe[1,2] — [1]RWTH Aachen University Chair for Laser Technology LLT — [2]Fraunhofer Institute for Laser Technology ILT

The possibility of diode pumping and the tunability between 700 nm and 800 nm make Alexandrite a remarkable laser gain medium. At present the scalability of the pump power and pump brilliance as well as the temporal stability of the laser output remain challenging. We report on our progress of using a red diode laser with spatially symmetrized output for end pumping of an Alexandrite laser rod. We measured the thermal dioptric power of the pumped laser crystal and experimentally identified the induced thermal aberrations as an important limit of the applicable pump power density. We designed a laser resonator with special emphasis on fundamental mode operation for high dioptric powers. We show results of a continuously pumped Alexandrite laser with wavelengths between 740 nm and 785 nm and fundamental mode operation up to 5 W. Future work will address further development of this laser in the field of mode locking and frequency conversion to generate ultrashort pulses and operate in the UV regime, respectively.

Q 13.2 Mon 14:15 K 0.023

Fourier Limited Picosecond Pulses for Laser Cooling of Relativistic Ion Beams — •Daniel Kiefer and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstr. 7, 64289, Darmstadt

Laser cooling of relativistic ion beams has been shown to be a sophisticated technology [1] and white light cooling has been demonstrated in non-relativistic ion beam cooling [2]. However, the experimental realisation of white-light-cooling of relativistic beams still has to be performed. The necessary laser bandwidth shall be provided by pulsed laser light. Simulations have shown the demanding requirements for these laser pulses [3]. We present a master-oscillator-power-amplifier system supplying laser pulses of 100 to 740 ps length with a centre wavelength of 1029 nm. The system is marked by the Fourier transform limited character of the pulses, the continuously adjustable pulse length and the repetition rate between 500 kHz and 10 MHz. [1] S. Schröder et al, Phys. Rev. Lett. 64, 2901-2904, (1990). [2] S.N.Atutov et al, Phys. Rev. Lett. 80, 2129, (1998). [3] L. Eidam et al, arXiv:1709.03338 [physics.acc-ph], (2017).

Q 13.3 Mon 14:30 K 0.023

Ultra Compact High-Harmonic Cavity Optical Parametric Oscillator for Optical Amplifier Seeding — •Marco Nägele[1], Florian Mörz[1], Heiko Linnenbank[1], Tobias Steinle[2], Andy Steinmann[1], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart, Germany — [2]ICFO, Barcelona, Spain

We present a master oscillator power amplifier (MOPA) scheme, based on a high-harmonic cavity optical parametric oscillator (OPO), emitting tunable light in the near infrared region. Different from conventional OPOs and our previous fiber-feedback OPO, the high-harmonic OPO cavity uses only a fraction of the fundamental conventional OPO cavity length, thus supporting the 15th harmonic and offering a very compact design. Additionally, low pump power values provide high suitability for post-amplification of the OPO output, since the remaining pump power is available for an optical parametric amplifier (OPA). We recorded a pump power threshold between 30-100 mW over the entire OPO tuning range from 2.3-4.1 μm. A high versatility of different pump laser sources with MHz repetition rate is suitable by using the high-harmonic cavity design and direct idler outcoupling. As the signal pulse remains inside the cavity, the ejected idler pulses match the pump laser in repetition rate, pulse duration, and shape. While we use a 450 fs pulsed solid-state pump laser at 1030 nm and 41 MHz, different repetition rate pump sources are usable by several cm cavity length adjustment in order to match a higher pump harmonic. Post amplification of the ejected idler using an (OPA) additionally generates tunable signal light between 1.4-2 μm.

Q 13.4 Mon 14:45 K 0.023

Noncollinear optical parametric oscillator for Raman Spectroscopy of Microplastics — •Luise Beichert[1], Yuliya Binhammer[1], José Ricardo Andrade[1], and Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Hannoversches Zentrum für optische Technologien, Leibniz Universität Hannover, Germany

Meanwhile microplastics can be detected in an increasing rate in our enviroment as well as in our drinking water. We present a broadband and fast tunable light source to detect these particles via stimulated Raman scattering in water circulation.

Noncollinear optical parametric oscillators (NOPOs) provide a good scalability in terms of output power, repetition rate and pulse energy. The instantaneous broadband frequency conversion combined with the special phase matching geometry in the nonlinear crystal enables a fast tunability without readjustment.

We show an IR-NOPO, rapidly tunable in 1 ms from 750 to 950 nm and Ramanspectra in the range of 500-3200 cm^{-1} of different plastic particles.

Q 13.5 Mon 15:00 K 0.023

Monitoring protein configurations in the fingerprint region with micro-FTIR spectroscopy using a 98 fs solid-state laser tunable from 1.33 to 8 μm at 73 MHz repetition rate — •Florian Mörz[1], Rostyslav Semenyshyn[1], Frank Neubrech[2], Tobias Steinle[3], Andy Steinmann[1], and Harald Giessen[1] — [1]4. Physikalisches Institut, Universität Stuttgart — [2]Kirchhoff-Institut für Physik, Universität Heidelberg — [3]ICFO-Institut de Ciencies Fotoniques, Barcelona, Spanien

Configurations of poly-L-lysine proteins using vibrational resonances at 6 μm (1667 cm-1) are monitored by employing a broadband femtosecond laser for micro-FTIR spectroscopy in combination with resonant surface-enhanced infrared absorption (SEIRA) spectroscopy, using a single gold nanoantenna. Our tabletop laser system exceeds the sensitivity of standard FTIR light sources due to an orders of magnitude higher brilliance. Absorption signals as small as 0.5% are detected without averaging, compared to 6.4% using a globar, at 10x10 μm^2 spatial resolution. By pumping a fiber-feedback optical parametric oscillator and a post-amplifier, signal and idler beams spanning from 1.33-2.0 and 2.1-4.6 μm are generated. The tuning range is extended to 8 μm by difference frequency generation between the signal and idler beams. At 7 μm a wavelength stability with fluctuations smaller than 0.1% rms over 9 hours is observed, without applying electronic stabilization. Thus our design is distinctly superior over other systems based on free-space OPOs and applications such as protein sensing using FTIR spectroscopy in combination with SEIRA are enabled.

Q 13.6 Mon 15:15 K 0.023

Systematic refractive index measurements of photo-resists for three-dimensional direct laser writing — •Michael Schmid and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Femtosecond 3D printing is an important technology for manufacturing of nano- and microscopic devices and elements. Crucial for the design of such structures is the detailed knowledge of the refractive index in the visible and near-infrared spectral range and its dispersion.

We characterize different photoresists that are used with femtosecond 3D direct laser writers, namely IP-S, IP-Dip, IP-L, and OrmoComp with a modified and automized Pulfrich refractometer setup, utilizing critical angles of total internal reflection. Thereby we achieve an accuracy of $5{\cdot}10^{-4}$ and reference our values to a BK-7 glass plate. Their refractive indices are in the 1.49-1.57 range, while their Abbe numbers are in the range between 35 and 51.

Furthermore, we systematically study the effects of UV exposure duration as well as the aging process on the refractive index of the photo resists which are crucial for 3D printed functional devices, especially nano- and microscopic devices. We also deliver the first measurements of refractive index of actual 3D printed samples.

Q 13.7 Mon 15:30 K 0.023

Atom Trap Trace Analysis: Pushing the volume limit for radiometric dating with applied quantum technology — •Lisa

Ringena[1], Zhongyi Feng[1], Sven Ebser[1], Maximilian Schmidt[1], Arne Kersting[2], Emeline Mathouchanh[2], Philip Hopkins[2], Viola Rädle[2], Werner Aeschbach[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Institut für Umweltphysik, Universität Heidelberg

Argon Trap Trace Analysis (ArTTA) applies quantum technology to establish an ultra-sensitive detection method for the radioisotope ^{39}Ar. This isotope, with a half-life of 269 years, serves as an unique tracer for dating of environmental samples. The atom of interest is distinguished from the huge background of abundant isotopes by utilizing its shift in optical resonance frequency due to differences in mass and nuclear spin. This selectivity is realized by the multitude of scattering processes in a magneto-optical trap (MOT), where single atoms are captured and detected [1]. Recently the instrument has been upgraded to operate with a minimum of 1mL STP argon gas, degassed from about 2.5L of water, drastically decreasing the effort invested in environmental studies such as ocean depth profiles, and making dating of glacier ice feasible. Paving the way towards routine operation, measures have been taken to increase the stability of the experiment, such as the setup of a new laser system. We will present systematic studies of the apparatus, which show a doubled count rate, leading to shorter measurement times and reduction of statistical errors.

[1] Ritterbusch et al., GRL 2014, DOI: 10.1002/2014GL061120

Q 14: Precision Spectrosocopy II - trapped ions (joint session A/Q)

Time: Monday 14:00–15:45 Location: K 1.016

Invited Talk Q 14.1 Mon 14:00 K 1.016
A ppb measurement of the antiproton magnetic moment — •C. Smorra[1], S. Sellner[1], M. Borchert[1,2], J. A. Harrington[3], T. Higuchi[1,4], H. Nagahama[1], A. Mooser[1], G. Schneider[1,5], M. Bohman[1,3], K. Blaum[3], Y. Matsuda[4], C. Ospelkaus[2,6], W. Quint[7], J. Walz[5,8], Y. Yamazaki[1], and S. Ulmer[1] — [1]RIKEN, Ulmer Fundamental Symmetries Laboratory, Wako, Saitama, Japan — [2]Leibniz Universität, Hannover, Germany — [3]Max-Planck Institute für Kernphysik, Heidelberg, Germany — [4]University of Tokyo, Tokyo, Japan — [5]Johannes Gutenberg-Universität, Mainz, Germany — [6]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [7]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [8]Helmholtz-Institut Mainz, Mainz, Germany

The BASE collaboration performs high-precision measurements of the fundamental properties of protons and antiprotons in a multi Penning-trap system. Such measurements challenge the Standard Model of particle physics, since any deviation in proton and antiproton properties would hint to yet unknown CPT-odd interactions that would act differently on matter and antimatter-conjugates.

We recently reported a measurement of the antiproton magnetic moment with 1.5 ppb uncertainty (68 % C.L.) based on the frequency ratio of the Larmor frequency to the cyclotron frequency measured with two single antiprotons. We apply a novel two-particle multi-trap scheme, which enhances the data accumulation rate compared to the double trap method. In this way, we improved limits on CPT-odd interactions on antiprotons by a factor 350.

Invited Talk Q 14.2 Mon 14:30 K 1.016
Towards laser cooling of atomic anions — •Alban Kellerbauer — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

Currently available cooling techniques for negatively charged particles allow cooling only to the temperature of the surrounding environment, typically a few kelvin. Laser cooling of atomic anions could be used to produce an ensemble of negative particles at microkelvin temperatures. These could sympathetically cool any species of negatively charged particles – from antiprotons to molecular anions – to ultracold temperatures. For this indirect cooling technique [1], a fast electronic transition is required. Until now, there are only three known atomic anions with bound–bound electric-dipole transitions. We have investigated these transitions in Os^- [2] and La^- [3] by high-resolution laser spectroscopy to test their suitability for laser cooling. The principle of the method, its potential applications, as well as recent experimental results will be presented.

[1] A. Kellerbauer & J. Walz, "A novel cooling scheme for antiprotons". New J. Phys. **8** (2006) 45. doi:10.1088/1367-2630/8/3/045.

[2] U. Warring *et al.*, "High-resolution laser spectroscopy on the negative osmium ion". Phys. Rev. Lett. **102** (2009) 043001. doi:10.1103/PhysRevLett.102.043001.

[3] E. Jordan *et al.*, "High-resolution spectroscopy on the laser-cooling candidate La^-". Phys. Rev. Lett. **115** (2015) 113001. doi:10.1103/PhysRevLett.115.113001.

Q 14.3 Mon 15:00 K 1.016
Towards Sympathetic Cooling of a Single Proton in a Penning Trap for a High-Precision Measurement of the Proton Magnetic Moment — •Markus Wiesinger[1,2], Matthew Bohman[1,2], Andreas Mooser[2], Georg Schneider[2,3], Natalie Schön[2,3,4], James Harrington[1], Takashi Higuchi[2,5], Stefan Sellner[2], Christian Smorra[2,7], Klaus Blaum[1], Yasuyuki Matsuda[5], Wolfgang Quint[6], Jochen Walz[3,4], and Stefan Ulmer[2] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Ulmer Fundamental Symmetries Laboratory, RIKEN, Wako, Japan — [3]Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany — [4]Helmholtz-Institut Mainz, Mainz, Germany — [5]Graduate School of Arts and Sciences, University of Tokyo, Tokyo, Japan — [6]GSI-Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [7]CERN, Geneva, Switzerland

Precise comparisons of the fundamental properties of protons and antiprotons, such as magnetic moments and charge-to-mass ratios, provide stringent tests of CPT invariance, and thus, matter-antimatter symmetry. Using advanced Penning-trap methods, we have recently determined the magnetic moments of the proton and the antiproton with fractional precisions on the p.p.b. level [1,2].

Both experiments rely on sub-thermal cooling of the particle's modified cyclotron mode using feedback-cooled tuned circuits. This time-consuming process is ultimately required to identify single spin quantum transitions with high detection fidelity, which is a major prerequisite to apply multi-trap methods.

In order to advance our techniques and to drastically reduce the measurement time, we are currently implementing methods to sympathetically cool protons and antiprotons by coupling them to laser-cooled beryllium ions, using a common endcap method [3]. In this talk we present the status of our ongoing efforts to deterministically prepare single protons and antiprotons at mK-temperatures.

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

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

[3] Heinzen, D. J. & Wineland, D. J. Phys. Rev. A, **42**, 2977 (1990)

Q 14.4 Mon 15:15 K 1.016
Resonant coupling of single protons and laser cooled Be ions — •Natalie Schön[1,2,7], Matthew Bohman[2,3], Andreas Mooser[2], Georg Schneider[1,2], Markus Wiesinger[2,3], James Harrington[3], Takashi Higuchi[2,4], Stefan Sellner[2], Christian Smorra[2,5], Klaus Blaum[3], Yasuyuki Matsuda[4], Wolfgang Quint[6], Jochen Walz[1,7], and Stefan Ulmer[2] — [1]University of Mainz, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, Japan — [3]MPIK Heidelberg, Germany — [4]University of Tokyo, Japan — [5]CERN, Switzerland — [6]GSI Darmstadt, Germany — [7]Helmholtz Institut Mainz, Germany

The relativistic quantum field theories of the Standard Model are invariant under the combined charge (C), parity (P) and time (T) transformation. To test this fundamental symmetry the BASE collaboration compares the g-factor and charge to mass ratio of protons and antiprotons with highest precision. Using Penning traps, we have recently performed 0.3 ppb and 1.5 ppb measurements of the proton and the antiproton g-factors, respectively. The uncertainties in the g-factor values are dominated by effects due to the energy of the trapped particle at 4 K. To overcome this limitation, we plan to resonantly couple the axial modes of laser cooled beryllium ions and of single (anti)protons. To match the axial frequencies a resonant circuit is used, which however heats the particles. Thus, after frequency matching, the resonant circuit will be decoupled from the ions by switching its resonance frequency. To this end several switches, with high isolation resistance and low insertion loss, were tested at cryogenic temperatures.

Q 14.5 Mon 15:30 K 1.016

Measurements with single antiprotons in an ultra-low noise Penning trap system — •Matthias Borchert[1,2], James Harrington[3], Takashi Higuchi[2,4], Jonathan Morgner[1,2], Hiroki Nagahama[2], Stefan Sellner[2], Christian Smorra[2], Matthew Bohman[2,3], Andreas Mooser[2], Georg Schneider[2,5], Natalie Schoen[5], Markus Wiesinger[2,3], Klaus Blaum[3], Yasuyuki Matsuda[4], Christian Ospelkaus[1,6], Wolfgang Quint[7], Jochen Walz[5,8], Yasunori Yamazaki[2], and Stefan Ulmer[2] — [1]Institut für Quantenoptik, Leibniz Univerisität Hannover, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, Wako, Japan — [3]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [4]Graduate School of Arts and Sciences, University of Tokyo, Japan — [5]Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany — [6]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [7]GSI - Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [8]Helmholtz-Institut Mainz, Germany

The observed baryon asymmetry in our Universe challenges the Standard Model of particle physics and motivates sensitive tests of CPT invariance. Inspired by that, the BASE experiment at CERN compares the fundamental properties of antiprotons and protons with high precision.

In 2014 we performed the most precise measurement of the antiproton charge-to-mass-ratio $q_{\bar{p}}/m_{\bar{p}}$ [1], with a fractional precision of 69 ppt. Very recently we reported on a 350-fold improved measurement of the antiproton magnetic moment $\mu_{\bar{p}}$ [2] using a newly-invented multi-Penning trap method. The high-precision measurement of $\mu_{\bar{p}}$ was enabled by a highly-stabilised experimental apparatus including ultra-low electric field fluctuations.

In this talk I will focus on the characterisation and optimisation of electric field noise and the interpretation of heating rates at different radial amplitudes causing axial frequency fluctuations. The optimised Penning trap heating rates measured in BASE are well below the heating rates which are usually reported in Paul traps. Furthermore, I will summarize recent experimental developments and discuss future prospects of BASE.

[1] Ulmer et al., *Nature* **524**, 196-199 (2015)
[2] Smorra et al., *Nature* **550**, 371-374 (2017)

Q 15: Quantum Information (Concepts and Methods) II

Time: Monday 14:00–16:00 Location: K 1.019

Group Report Q 15.1 Mon 14:00 K 1.019

Pushing the Limits of Reachable States by Optimal Control — •Thomas Schulte-Herbrüggen[1], Ville Bergholm[1,2], Frank K. Wilhelm[3], and Michael Keyl[4] — [1]Technical University of Munich (TUM) — [2]University of Helsinki — [3]University of Saarbrücken — [4]Dahlem Centre for Complex Quantum Systems, FU-Berlin

Resorting to optimal control methods often is key to achieving high fidelity in actual experiments. Examples meanwhile pertain to quantum information processing, quantum simulation, and quantum sensing.

Recently, we have extended our optimal-control platform dynamo by allowing for fast switchable noise on top of coherent controls. We suggested implementation by superconducting qudits (GMons) with tunable coupling to an open transmission line.

Here we show how to use these features as internal cooling device replacing measurement-based closed-loop feedback control for arbitrary interconversion between quantum states (pure or mixed). Finally, we give an outlook on further experimental implementations, where optimal control paves the way to achieving unprecedented states.

Q 15.2 Mon 14:30 K 1.019

Precision bounds for gradient magnetometry with atomic ensembles — •Iagoba Apellaniz[1], Iñigo Urizar-Lanz[1], Zoltán Zimborás[1,2,3], Philipp Hyllus[1], and Géza Tóth[1,3,4] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [4]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain

We study gradient magnetometry with an ensemble of atoms with arbitrary spin. We consider the case of a very general spatial probability distribution function. We calculate precision bounds for estimating the gradient of the magnetic field based on the quantum Fisher information. For quantum states that are invariant under homogeneous magnetic fields, we need to measure a single observable to estimate the gradient. On the other hand, for states that are sensitive to homogeneous fields, the measurement of two observables are needed, as the homogeneous field must also be estimated. This leads to a two-parameter estimation problem. We present a method to calculate precision bounds for gradient estimation with a chain of atoms or with two spatially separated atomic ensembles feeling different magnetic fields. We also consider a single atomic ensemble with an arbitrary density profile, in which the atoms cannot be addressed individually, and which is a very relevant case for experiments. Our model can take into account even correlations between particle positions.

Q 15.3 Mon 14:45 K 1.019

Lower bounds on the quantum Fisher information based on the variance and various types of entropies — •Géza Tóth — Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — Wigner Research Centre for Physics, H-1525 Budapest, Hungary — IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain

We examine important properties of the difference between the variance and the quantum Fisher information over four, i.e., var(A)-F_Q[rho,A]/4. We find that it is equal to a generalized variance defined in Petz [J. Phys. A 35, 929 (2002)] and Gibilisco, Hiai, and Petz [IEEE Trans. Inf. Theory 55, 439 (2009)]. We present an upper bound on this quantity that is proportional to the linear entropy. As expected, our relations show that for states that are close to being pure, the quantum Fisher information over four is close to the variance. We also obtain the variance and the quantum Fisher averaged over all Hermitian operators, and examine their relation to the von Neumann entropy.

Q 15.4 Mon 15:00 K 1.019

Information Disturbance Tradeoff in Quantum Measurement — Lukas Knips[1,2], •Jan Dziewior[1,2], Anna-Lena Hashagen[3], Jasmin Meinecke[1,2], Michael Wolf[3], and Harald Weinfurter[1,2] — [1]Department for Physics, LMU, 80797 Munich — [2]Max-Planck-Institute for Quantum Optics, 85748 Garching — [3]Zentrum Mathematik, TUM, 85748 Garching

One of the most characteristic features of quantum mechanics is that every measurement which extracts information from a physical system necessarily causes an irreducible disturbance. While this fundamental complementarity has been considered in numerous works, recently an analysis of unprecedented generality has been performed [1]. In particular it provides a dimension-independent optimal tradeoff relation for general von Neumann measurements based on the cb-norm for quantum channels as a distance measure. We evaluate this relation experimentally for the observation of a qubit by implementing the full range of possible measurements and determining the amount of accessible information for a given disturbance. The various measurements are realized by a tunable Mach-Zehnder-Interferometer, which supplies the ancillary degrees of freedom necessary to implement arbitrary POVMs and quantum channels for the measurement of a polarization qubit. Not only are we able to show the validity of the fundamental bound, but, furthermore, achieve the demonstration of its tightness by saturating it with high significance.

[1] Hashagen, A., Wolf, M., Universality and Optimality in the Information-Disturbance Tradeoff, in preparation.

Q 15.5 Mon 15:15 K 1.019

Reduction of a quantum state in time-of-flight measurements — •Fabio Di Pumpo and Matthias Freyberger — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, D-89069 Ulm

We discuss quantum mechanical time-of-flight momentum measurements, which are motivated by the classical time-of-flight concept. Our setup is modeled by a Hamiltonian for a free particle interacting with two quantum pointers. For this model we can solve the corresponding three-particle dynamics in the Heisenberg picture. This allows us to examine two fundamental aspects: First, we verify that the expectation value of the operational momentum operator equals the one of the original momentum operator describing the single-particle system. Second, we analyze in what sense position measurements on the pointers reduce the conditional quantum state of the particle and hence define its momentum.

Q 15.6 Mon 15:30 K 1.019

Prime number decomposition using the Talbot effect — Karl Pelka[1], •Jasmin Graf[1], Thomas Mehringer[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany

The Talbot effect is a near field diffraction effect describing the self imaging of a coherently illuminated transmission grating. Mathematically, this effect can be described by Gauss sums, which are connected to prime number decomposition. We present a novel algorithm for prime factorization which exploits the appearance of Gauss sums in the near field intensity distribution behind a single slit of the grating. We discuss the theoretical framework of this algorithm and report on an experimental implementation displaying an impressive agreement with the theoretical predictions.

We also investigate the regime of an incoherently illuminated grating where no first order interference signal is obtained. However, all relevant information can be regained by measuring the intensity correlations of second order. We explain how Gauss sums appear in the second order correlation function and how this signal can be used for prime number decomposition. As an outlook we present the experimental setup for measuring incoherent Talbot-like effects.

Q 15.7 Mon 15:45 K 1.019

Assessing and tailoring the quantumness of damped two-level-systems — •Alexander Friedenberger and Eric Lutz — Friedrich-Alexander-Universität Erlangen

One of the lynchpins for the conception and application of quantum technologies is the identification and harnessing of nonclassical properties of a given system. We perform a detailed analysis of the nonclassical properties of a damped two-level system. We discuss how these properties can be tuned with the help of external driving fields. We show in particular how the nonclassicality of a two-level system can be maximized at any desired time by choosing an appropriate driving field.

Q 16: Quantum Information and Simulation

Time: Monday 14:00–15:45 Location: K 1.020

Q 16.1 Mon 14:00 K 1.020

Improving the consistency of a quantum experiment with reinforcement learning — •Sabine Wölk and Hans Jürgen Briegel — Institute for Theoretical Physics, University of Innsbruck, 6020 Innsbruck, Austria

In quantum experiments, expectation values of observables are determined by repeating their measurement many times. Meaningful results can only be obtained if the conditions under which the experiment is performed can be kept constant for all the measurements. For setups with unstable conditions, e.g. frequency drift, this may require calibration measurements during data acquisition, which however increases the amount of resources, e.g., time, number of qubits, or general equipment. The problem of finding an optimal calibration strategy is in general highly non-trivial since the only available information is probabilistic.

We show that a learning agent using projective simulation [1] is able to find good solutions based solely on the experimental data. In this way, we also demonstrate that projective simulation is not limited to deterministic rewards but can also learn from probabilistic ones.

[1] H. J. Briegel and G. De las Cuevas, Sci. Rep. **2**, 400 (2012)

Q 16.2 Mon 14:15 K 1.020

Open quantum generalisation of classical Hopfield neural networks — •Eliana Fiorelli[1,2], Pietro Rotondo[1,2], Matteo Marcuzzi[1,2], Juan P Garrahan[1,2], Markus Muller[3], and Igor Lesanovsky[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham — [3]Department of Physics, Swansea University, Singleton Park, Swansea SA2 8PP, UK

Neural networks (NNs) are artificial networks inspired by the interconnected structure of neurons in animal brains. They are now capable of computational tasks where most ordinary algorithms would fail, such as speech and pattern recognition, with a wide range of applicability both within and outside research. Hopfield NNs [1] constitute a simple, but rich example of how an associative memory can work; they have the ability to retrieve, from a set of stored network states, the one which is closest to the input pattern. In the last decades, many models have been proposed in order to combine the properties of NNs with quantum mechanics, aiming at understanding if NNs computing can take advantage from quantum effects. Here we discuss a quantum generalisation of a classical Hopfield model [2] whose dynamics is governed by purely dissipative, yet quantum, processes. We show that this dynamics may indeed yield an advantage over a purely classical one, leading to a shorter retrieval time. [1] J.J. Hopfield, Proceedings of the National Academy of Sciences, 79, 2554, (1982) [2] P. Rotondo et al., arXiv:1701.01727 (2017).

Q 16.3 Mon 14:30 K 1.020

Projective simulation memory network for solving toy and complex problems — •Alexey Melnikov[1], Vedran Dunjko[2], Hendrik Poulsen Nautrup[1], and Hans Briegel[1,3] — [1]Institute for Theoretical Physics, University of Innsbruck — [2]Max-Planck-Institute for Quantum Optics — [3]Department of Philosophy, University of Konstanz

The projective simulation (PS) model is a physical approach to artificial intelligence. In the PS model, learning is realized by internal modification of the episodic memory network, both in terms of its structure and the weights of its edges. Through interactions with a task environment, the PS memory network adjusts itself dynamically, so as to increase the probability of performing better in subsequent time steps. Here we consider several examples of environments, in which the PS agent does self-adjustments due to the glow, the generalization and the meta-learning mechanisms. The emphasis is made on examples of the PS agent applied to quantum optics experiments in which the agent autonomously learns to reach various entanglement classes.

Q 16.4 Mon 14:45 K 1.020

Projective simulation applied to non-Markovian problems — •Lea M. Trenkwalder[1], Vedran Dunjko[2], and Hans J. Briegel[1] — [1]University of Innsbruck — [2]MPI for Quantum Optics

The idea of machines acquiring complex behaviour can be studied in terms of learning agents. In reinforcement learning models, an agent learns through interaction with an environment, as it receives rewards and information about the environment in terms of percepts. An agent is confronted with a Markovian task environment if a given percept contains all the information needed to determine the probability distribution over the subsequent environmental states. Projective simulation (PS) is a novel learning model, which has been used to solve a variety of Markovian reinforcement learning tasks. The projective simulation model is a physics-inspired approach where the internal deliberation process of the agent can be described by a random walk through its episodic memory. Moreover, this random walk possesses a quantum analogue, providing the PS framework with a natural route to quantisation. For a variant of PS called rPS, it was proven that quantum effects can be exploited to achieve a quadratic speed-up in its active learning time. Recently, it was shown that complex Markovian task environments such as the design of certain quantum experiments, can be tackled using PS. In the present work, we generalise projective simulation to solve a set of non-Markovian problems, in which the perceptual input does not enclose all the information needed to determine the development of the environment. The approach allows the projective simulation model to be applied to a wider range of task environments.

Q 16.5 Mon 15:00 K 1.020

Using quantum physics to simulate discrete-time, highly non-Markovian complex processes — •Felix Binder[1], Jayne Thompson[2], Chengran Yang[1], Varun Narasimhachar[1], and Mile Gu[1,2,3] — [1]School of Physical and Mathematical Sciences, Nanyang Technological University, 637371 Singapore, Singapore — [2]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, 117543 Singapore, Singapore — [3]Complexity Institute, Nanyang Technological University, 639673, Singapore

Stochastic processes are as ubiquitous throughout the quantitative sciences as they are notorious for being difficult to simulate and predict. In this talk I present a unitary quantum simulator for discrete-time stochastic processes which requires less internal memory than any classical analogue throughout the simulation. The simulator's internal memory requirements equal those of the best previous quantum models. However, in contrast to previous models it only requires a (small) finite-dimensional Hilbert space. Moreover, since the simulator operates unitarily throughout, it avoids any unnecessary information loss. Interestingly, the formalism of matrix product states may be used to systematically derive the memory states and the unitary operator which define the simulator. This renders the results useful for direct experimental implementation with current platforms for quantum computation and I will present results obtained from simulation on IBM's Quantum Experience for a representative example process.

Q 16.6 Mon 15:15 K 1.020

Modeling the atomtronic analog of an optical polarizing beam splitter, a half-wave plate, and a quarter-wave plate for phonons of the motional state of two trapped atoms — •Naeimeh Mohseni[1,2], Marjan Fani[3], Jonathan Dowling[4], and Shahpoor Saeidian[1] — [1]Department of Physics, Institute for Advanced Studies in Basic Sciences, Zanjan, Iran. — [2]Max Planck institute for the science of the light — [3]Department of Physics, University of Isfahan, Isfahan, Iran — [4]Hearne Institute for Theoretical Physics and Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803, USA

We propose a scheme to model the phonon analog of optical elements, including a polarizing beam splitter, a half-wave plate, and a quarter-wave plate, as well as an implementation of CNOT and Pauli gates, by using two atoms confined in a two-dimensional plane. The internal states of the atoms are taken to be Rydberg circular states. Using this model we can manipulate the motional state of the atom, with possible applications in optomechanical integrated circuits for quantum information processing and quantum simulation. Towards this aim, we consider two trapped atoms and let only one of them interact simultaneously with two circularly polarized Laguerre-Gaussian beams.

Q 16.7 Mon 15:30 K 1.020

Holography and criticality in matchgate tensor networks — Alexander Jahn, •Marek Gluza, Fernando Pastawski, and Jens Eisert — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

The AdS/CFT correspondence conjectures a holographic duality between gravity in a bulk space and a critical quantum field theory on its boundary. Tensor networks have come to provide toy models to understand such bulk-boundary correspondences, shedding light on connections between geometry and entanglement. We introduce a versatile and efficient framework for studying tensor networks, extending previous tools for Gaussian matchgate tensors in $1 + 1$ dimensions. Using regular bulk tilings, we show that the critical Ising theory can be realized on the boundary of both flat and hyperbolic bulk lattices. Within our framework, we also produce translation-invariant critical states by an efficiently contractible network dual to the multi-scale entanglement renormalization ansatz. Furthermore, we explore the correlation structure of states emerging in holographic quantum error correction. We hope that our work will stimulate a comprehensive study of tensor-network models capturing bulk-boundary correspondences.

Q 17: Bose-Einstein Condensation (joint session A/Q)

Time: Monday 14:00–16:15 Location: K 2.016

Q 17.1 Mon 14:00 K 2.016

Nonequilibrium Quantum Phase Transition in a Hybrid Atom-Optomechanical System — •Niklas Mann[1], M. Reza Bakhtiari[1], Axel Pelster[2], and Michael Thorwart[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany — [2]Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

We consider a hybrid quantum many-body system formed by both a vibrational mode of a nanomembrane, which interacts optomechanically with light in a cavity, and an ultracold atom gas in the optical lattice of the out-coupled light. After integrating over the light field, an effective Hamiltonian reveals a competition between the localizing potential force and the membrane displacement force. For increasing atom-membrane interaction we find a nonequilibrium quantum phase transition from a localized non-motional phase of the atom cloud to a phase of collective motion. Near the quantum critical point, the energy of the lowest collective excitation vanishes, while the order parameter of the condensate becomes non-zero in the symmetry-broken state. The effect occurs when the atoms and the membrane are non-resonantly coupled.

Q 17.2 Mon 14:15 K 2.016

Second sound across the BEC-BCS crossover — •Vijay Pal Singh[1,2,3], Daniel Kai Hoffmann[4], Thomas Paintner[4], Wolfgang Limmer[4], Johannes Hecker Denschlag[4], and Ludwig Mathey[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, Hamburg 22761, Germany — [4]Institut für Quantenmaterie, Universität Ulm, 89081 Ulm, Germany

We report on the first and second sound measurements across the BEC-BCS crossover and their theoretical analysis. The measurements are performed in a cigar-shaped three-dimensional cloud of ^{6}Li atoms and molecules. First sound is excited by an external potential that couples to the density, while second sound is excited by a potential modulation resulting mainly in local heating. The velocity of first and second sound is extracted from the propagation of the excited density wave. We find that the second sound velocity is reduced with decreasing cloud density and vanishes at the superfluid-thermal boundary, whereas the first sound velocity is only weakly affected by the cloud density. We compare the experiments on the BEC side of the crossover to numerical simulations and find good agreement.

Q 17.3 Mon 14:30 K 2.016

Zeeman Effect in Spinor Condensates: Tuning the Mott-Superfluid transition and the Nematic Order — •Laurent de Forges de Parny[1] and Valy Rousseau[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]Physics Department, Loyola University New Orleans, 6363 Saint Charles Ave., LA 70118, USA

Spinor condensates, namely Bose-Einstein condensates with internal degree of freedom, allow for the investigation of quantum magnetism [1]. When loaded into an optical lattice, these systems can be described by an extended Bose-Hubbard model with spin-spin interactions [2]. Using quantum Monte Carlo simulations, we study the Zeeman effect in a system of antiferromagnetic spin-1 bosons trapped in a square lattice at zero temperature. The Zeeman effect strongly affects the Mott-superfluid transition and the magnetic properties, e.g. the singlet state and the nematic order.

[1] D. M. Stamper-Kurn and M. Ueda, Rev. Mod. Phys. 85, 1191 (2013);

[2] A. Imambekov, M. Lukin, and E. Demler, Phys. Rev. A 68, 063602 (2003).

Q 17.4 Mon 14:45 K 2.016

Spatial entanglement and Einstein-Podolsky-Rosen steering in a Bose-Einstein condensate — •Tilman Zibold, Matteo

Fadel, Boris Décamps, and Philipp Treutlein — Department of Physics, University of Basel, Basel, Switzerland

We investigate the spatial entanglement in a spin squeezed Bose-Einstein condensate of rubidium atoms. By letting the atomic cloud expand and using high resolution absorption imaging we are able to access the spatial spin distribution of the many-body state. The observed spin correlations between different regions go beyond classical correlations and reveal spatial non-separability. Furthermore they allow for EPR steering of a subregion of the atomic spin. By inferring measurement outcomes of non-commuting observables in one region based on measurements in a separate region we are able to seemingly beat the Heisenberg uncertainty relation, realizing the EPR paradox with an atomic system. Our findings could be relevant for future quantum enhanced measurements of spatially varying observables such as electromagnetic fields.

Q 17.5 Mon 15:00 K 2.016

A coherent perfect absorber for matter waves — •Jens Benary[1], Andreas Müllers[1], Bodhaditya Santra[1], Christian Baals[1,2], Jian Jiang[1], Ralf Labouvie[1,2], Dmitry A. Zezyulin[3,4], Vladimir V. Konotop[4], and Herwig Ott[1] — [1]Department of Physics and OPTIMAS research center, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, 55128 Mainz, Germany — [3]ITMO University, St. Petersburg 197101, Russia — [4]Centro de Física teórica e Computacional and Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa 1749-016, Portugal

A coherent perfect absorber is a system in which complete absorption of incoming radiation is achieved by a spatially localized absorber embedded in a wave-guiding medium. The concept of coherent perfect absorption (CPA) was introduced [1] for light interacting with absorbing scatterers. The phenomenon is based on the destructive interference of the transmitted and reflected waves. Extending the paradigm of CPA to nonlinear matter waves we find that the conditions for CPA can be achieved easier than in the linear case. This is due to the combination of a nonlinear medium with localized absorption stabilizing the system. We experimentally demonstrate CPA for matter waves with an atomic Bose-Einstein condensate of Rb-87 in a one-dimensional periodic potential with an absorbing lattice site. This absorption is tailored via an electron beam which locally induces losses.

[1] Y. D. Chong , L. Ge, H. Cao and A. D. Stone, Coherent Perfect Absorbers: Time-Reversed Lasers. Phys. Rev. Lett. 105 053901 (2010)

Q 17.6 Mon 15:15 K 2.016

Phase separation dynamics in a many-body Binary Bose-Einstein condensate — •Simeon Mistakidis[1], Garyfallia Katsimiga[1], Panagiotis Kevrekidis[2], and Peter Schmelcher[1,3] — [1]Zentrum für optische Quantentechnologien Luruper Chaussee 149 22761 Hamburg — [2]Department of Mathematics and Statistics, University of Massachusetts Amherst, Amherst, MA 01003-4515, USA — [3]The Hamburg Centre for Ultrafast Imaging, Universitat Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

The many-body quenched dynamics of a binary mixture crossing the miscibility-immiscibility boundary and vice versa, is examine. Increasing the interspecies repulsion leads to the filamentation of the density of each component, involving shorter wavenumbers (and longer spatial scales) in the many-body approach. These filaments appear to be strongly correlated both at the one- and the two-body level, exhibiting domain-wall structures. Furthermore, following the reverse quench process dark-bright soliton trains are spontaneously generated and subsequently found to decay in the many-body scenario. We utilize single-shot images to provide a clean experimental realization of our current findings via which the filamentation process is clearly captured. To expose further the many-body nature of the observed dynamics direct measurements of the variance of single-shots are performed, verifying the presence of fragmentation but also the entanglement between the species.

Q 17.7 Mon 15:30 K 2.016

Approaching Steady-State Quantum Degeneracy — •Shayne Bennetts, Chun-Chia Chen, Rodrigo Gonzalez Escudero, Benjamin Pasquiou, and Florian Schreck — Institute of Physics, University of Amsterdam

So far BECs and atom lasers have only been demonstrated as the product of a time sequential, pulsed cooling scheme. Here we will describe a steady-state system demonstrating phase-space densities (PSD) approaching degeneracy. By flowing atoms through a series of spatially separated cooling stages and employing a range of novel tricks we recently demonstrated a steady-state strontium MOT with a PSD above 10^{-3} [1], 100 times higher than previous experiments. Now we demonstrate a set of tools, compatible with steady-state operation, to continuously cool and transfer microkelvin-cold atoms from a MOT into a dipole trap reservoir. Furthermore, by combining our novel machine architecture with a lighshift engineering technique we previously demonstrated [2], we protect a BEC from the strong fluorescence of a nearby MOT. Using all these tools on our high PSD MOT, quantum degeneracy in a steady-state system seems at reach. A steady-state source of degenerate atoms offers great advantages for applications such as next generation degenerate atomic clocks, super-radiant lasers or atom-interferometers for gravitational wave detection.

[1] S. Bennetts *et al.*, Phys. Rev. Lett. 119, 223202 (2017).
[2] S. Stellmer *et al.*, Phys. Rev. Lett. 110, 263003 (2013).

Q 17.8 Mon 15:45 K 2.016

Role of thermal phonon scattering for impurity dynamics in low-dimensional BEC — •Tobias Lausch, Artur Widera, and Michael Fleischhauer — TU Kaiserslautern and Forschungszentrum OPTIMAS, Erwin-Schroedinger-Strasse 46, 67663 Kaiserslautern, Germany

Ultracold gases have proven powerful systems to engineer quantum systems, paving the way for quantum simulations of solid state phenomena. An intriguing focus of research lies on impurity systems, aiming on elucidating microscopic properties of thermalization or quasi-particle formation in quantum systems.

We theoretically study the immersion of single impurities into a BEC in different spatial-dimensions and solve a Boltzmann equation to analyze the non-equilibrium dynamics. We find that high order scattering processes, such as two phonon scattering, dominate the impurities cooling dynamics in low dimensional BEC even at low (experimentally accessible) finite temperatures. In fact, these two-phonon scattering processes are the microscopic mechanism reflecting the famous Mermin-Wagner-Hohenberg theorem. Our work undelines the necessity to include higher-order scattering terms in the investigation of low-dimensional impurity physics.

Q 17.9 Mon 16:00 K 2.016

Prospects for studying atom-ion interaction with giant Rydberg atoms in a Bose-Einstein condensate — •Felix Engel, Kathrin Kleinbach, Thomas Dieterle, Carolin Dietrich, Robert Löw, Florian Meinert, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Germany

Giant Rydberg atoms immersed in ultracold quantum gases realize situations where thousands of ground-state atoms reside within the Rydberg electron orbit. In our experiments, we study the interaction of a single highly excited Rydberg electron ($n \sim 200$) with a Bose-Einstein condensate (BEC). The interaction of the Rydberg electron with the condensate atoms causes a density-dependent spectral line shift and broadening of the Rydberg excitation, which reflects the underlying scattering physics.

Using a tightly focused optical microtrap we access a parameter regime for which the Rydberg electron orbit largely exceeds the spatial extent of the BEC. This reduces the contribution of electron-neutral interaction with increasing n to the observed excitation spectrum. Consequently, the interaction of the condensate atoms with the Rydberg ionic core is expected to actively shape the spectral response, which provides an appealing route to study atom-ion interaction in a BEC.

Q 18: Quantum Gases (Bosons) II

Time: Monday 14:00–16:00 Location: K 2.020

Q 18.1 Mon 14:00 K 2.020

Observation of parametric instabilities in 1D interacting shaken optical lattice systems — •Jakob Näger[1,2], Karen Wintersperger[1,2], Marin Bokov[3], Martin Reitter[1,2], Samuel Lellouch[4], Ulrich Schneider[5], Nathan Goldman[4], Immanuel Bloch[1,2], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstr. 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching — [3]Boston University, 590 Commonwealth Ave., Boston, MA 02215 — [4]Université Libre de Bruxelles, CP 231, Campus Plaine, 1050 Brussels, Belgium — [5]University of Cambridge, Cambridge, UK

We study the dynamics of BECs in a driven optical 1D lattice using 39K atoms that have an accessible Feshbach resonance allowing for the control of interactions. The short-time dynamics is mostly dominated by parametric instabilities [1] and can be well described within Bogoliubov theory. At longer times this description seizes to be accurate and the dynamics can be captured by a Fermi*s golden rule approach [2]. We observe the transition between the two regimes for different shaking parameters and interactions. Also, we compare the quasimomentum of the most unstable modes to the values expected from Bogoliubov theory.

[1] S. Lellouch et al., PRX 7, 021015, 2017
[2] M. Reitter et al., PRL 119, 200402, 2017

Q 18.2 Mon 14:15 K 2.020

Creating a superfluid by kinetically driving a Mott insulator — •Gregor Pieplow, Charles E. Creffield, and Fernando Sols — Departamento de Física de Materiales, Universidad Complutense de Madrid, E-28040 Madrid, Spain

We study the effect of time-periodically varying the hopping amplitude (which we term “kinetic driving”) in a one-dimensional Bose-Hubbard model, such that the time-averaged hopping is zero. By using Floquet analysis we derive a static effective Hamiltonian in which nearest-neighbor single-particle hopping processes are suppressed, but all even higher-order processes are allowed. Unusual many-body features arise from the combined effect of nonlocal interactions and correlated tunneling. At a critical value of the driving, the system passes from a Mott insulator to a superfluid formed by two quasi-condensates with opposite nonzero momenta. A many-body cat state combining the two macroscopically-occupied momentum eigenstates emerges even with hard-wall boundary conditions. We also explore Bogoliubov-de Gennes theory, which allows to infer the nature of the excitations of the fragmented superfluid. This work shows how driving of the hopping energy provides a novel form of Floquet engineering, which enables atypical Hamiltonians and exotic states of matter to be produced and controlled.

Q 18.3 Mon 14:30 K 2.020

Periodically Modulated Interaction of Two Species Bosons on the Optical Lattice — •Shijie Hu[1], Tao Wang[2], Axel Pelster[1], Sebastian Eggert[1], and Xue-Feng Zhang[3] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Wuhan Institute of Technology, Hubei, China — [3]Chongqing University, Chongqing, China

Systems far away from equilibrium show interesting new phenomena. In this work, we propose to generate a periodically driven system of two species of bosons on a one-dimensional optical lattice by modulating the magnetic field nearby a Feshbach resonance. We further investigate properties of this system by various numerical methods. Surprisingly, at zero-temperature we found that the driving is not always suppressing the superfluid order; instead it can abnormally enhance the order in a specific parameter region. In other regions, the driving can induce a new kind of superfluid order because the cooperation of particles and gauge phases. The results are consistent with a rigorous solution at an integrable point. We also discuss the behaviour at finite temperatures.

Q 18.4 Mon 14:45 K 2.020

Generation of robust entangled states in a non-Hermitian periodically driven two-band Bose-Hubbard system — Carlos A. Parra-Murillo[1], Manuel H. Muñoz-Arias[1], •Javier Madroñero[1], and Sandro Wimberger[2] — [1]Physics Department, Universidad del Valle, Cali, Colombia — [2]Dipartimento di Scienze Matematiche, Fisiche e Informatiche Università di Parma, Italy

A many-body Wannier-Stark system coupled to an effective reservoir is studied within a non-Hermitian approach in the presence of a periodic driving. We show how the interplay of dissipation and driving dynamically induces a subspace of states which are very robust against dissipation. We numerically probe the structure of these asymptotic states and their robustness to imperfections in the initial-state preparation and to the size of the system. Moreover, the asymptotic states are found to be strongly entangled making them interesting for further applications.

Q 18.5 Mon 15:00 K 2.020

Periodic-Orbit Classification in Quantum Many-Body Systems — •Daniel Waltner, Maram Akila, Petr Braun, Boris Gutkin, and Thomas Guhr — Faculty of Physics, University of Duisburg-Essen, Duisburg, Germany

Semiclassical theories connect classical and quantum systems. They relate classical periodic orbits on the one side and the quantum spectrum on the other by trace formulae. In the past, there has been huge interest in obtaining periodic orbit spectra for single-particle quantum systems (for example for the hydrogen atom in a strong magnetic field and billiards). Here, the Fourier transformation of the trace formula was compared with the periodic orbits calculated by the classical equations of motion. In this presentation, I demonstrate how to generalize this comparison to a many-particle system considering a kicked spin chain with nearest neighbor Ising coupling and on-site kicked magnetic field. Here, we face the problem that the dimension of the quantum Hilbert space and the number of periodic orbits is too large to apply the conventional methods used for single-particle systems. We show how to overcome the problem arising from the large Hilbert space dimension by a duality relation and identify dominant contributions to the quantum spectrum arising from collective classical motion of the spins.

Reference: M. Akila, D. Waltner, B. Gutkin, P. Braun, T. Guhr, Phys. Rev. Lett. **118** (2017) 164101

Q 18.6 Mon 15:15 K 2.020

A Diagrammatic Monte Carlo study of a composite, rotating impurity — •Giacomo Bighin[1], Timur Tscherbul[2], and Mikhail Lemeshko[1] — [1]IST Austria (Institute of Science and Technology Austria), Am Campus 1, 3400 Klosterneuburg, Austria — [2]Department of Physics, University of Nevada, Reno, NV, 89557, USA

The angulon quasiparticle [1], formalizing the concept of a composite, rotating impurity interacting with a quantum many-body environment, has proven useful in the description of several experimental settings: cold molecules in a Bose-Einstein condensate or embedded in helium nanodroplets, electronic excitations in a BEC or in a solid.

Recently it has been shown that the angulon can be understood using a diagrammatic formalism [2], fusing Feynman diagrams with the angular momentum diagrams used in atomic and nuclear structure calculations. Based on this formalism, we present a comprehensive Diagrammatic Monte Carlo (DiagMC) study of the angulon.

The techniques we introduce open up the possibility of studying the angulon at arbitrary coupling strength, and are compared with existing weak- and strong- coupling analytical theories for the angulon [1]. The present work paves the way for using DiagMC techniques in the study of many-body systems comprising complex, rotating impurities, establishing a far-reaching connection between DiagMC techniques and molecular simulations.

[1] R. Schmidt and M. Lemeshko, Phys. Rev. Lett. 114, 203001 (2015) and Phys. Rev. X 6, 011012 (2016). [2] G. Bighin and M. Lemeshko, Phys. Rev. B 96, 419 (2017).

Q 18.7 Mon 15:30 K 2.020

Is there a Floquet Lindbladian? — •Alexander Schnell[1,3], André Eckardt[1,3], and Sergey Denisov[2,3] — [1]Max Planck Institut für Physik komplexer Systeme, Dresden, Germany — [2]Universität Augsburg, Germany — [3]Institute for Basic Science, Center for Theoretical Physics of Complex Systems, Daejeon, South Korea

It is well known that the stroboscopic dynamics of a time-periodically driven closed quantum system can be mapped to the dynamics of a time-independent Floquet Hamiltonian acting on the identical Hilbert space. For cold atom systems this concept has been applied successfully to shaken optical lattices, giving rise to e.g. artificial gauge fields for charge neutral atoms [1].

We address the question if a similar mapping exists for time-periodically driven open quantum systems, whose dynamics is governed by a Lindblad superoperator. We find that for a simple qubit model there are extensive parameter regions where a mapping to a time-independent Floquet Lindbladian is possible, and extensive regions where it is not. In the regions where this mapping fails the stroboscopic dynamics can only be reproduced by a time-homogeneous evolution that is non-markovian.

[1] A. Eckardt, Rev. Mod. Phys. 89, 011004 (2017)

Q 18.8 Mon 15:45 K 2.020

Excitation transport in networks with an energy gradient, modelled after photosynthetic systems — Hlér Kristjánsson[1,2], Jonathan Brugger[1], Gabriel Dufour[1], •Christian Scheppach[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg i. Br., Germany — [2]Department of Physics, Imperial College London, U.K.

In photosynthesis, a photon is absorbed by a light-harvesting antenna, and the energy excitation is transported along several chlorophylls to a reaction centre. Recently, there has been much discussion whether a quantum mechanically coherent description of the transport process is necessary to understand it. This motivates our theoretical study of excitation transport through networks of two-level systems. To account for the limited experimental knowledge of the parameters, as well as the natural variability in biological systems, we study statistical ensembles of networks and look for design principles ensuring efficient transport. When the input and output site of the network have the same energy, "centrosymmetry" of the Hamiltonian and a "dominant doublet" are design principles enhancing the probability of efficient transport. In the more realistic case of an energy difference between the input and output site, external vibrations can bridge the gap, and are treated with Floquet theory. Here, one can demand a "dominant Floquet doublet", and "anticentrosymmetry" can be imposed in the extended Floquet-Hilbert space.

Q 19: Cold atoms IV - topological systems (joint session A/Q)

Time: Monday 16:15–17:30 Location: K 0.011

Q 19.1 Mon 16:15 K 0.011

Properties of the one-particle density matrix in an interacting Chern insulator — •Andrew Hayward[1], Marie Piraud[2], and Fabian Heidrich-Meisner[2,3] — [1]LMU, Munich, Germany — [2]TU, Munich, Germany — [3]Georg-August-University Goettingen, Germany

The notion of a topological insulator is rooted in the physics of non-interacting particles but generalizes to interacting systems. Here we investigate how much the topological properties of an interacting Chern insulator are encoded in the single-particle quantities derived from the one-particle density matrix (OPDM) computed in the many-body ground state. The diagonalization of the OPDM yields the occupation spectrum and its eigenfunctions. In a concrete example we study how the occupations evolve as a function of interactions and how the eigenfunctions are deformed away from the non-interacting limit. After resolving potential ambiguities in defining OPDM eigenbands,we compute the Chern numbers for these emergent OPDM bands,which are necessarily quantized. The behavior of these quantities, occupations, OPDM eigenfunctions, and OPDM Chern numbers, across a transition into a topologically trivial phase is discussed.This research is supported by DFG Research Unit FOR2414.

Q 19.2 Mon 16:30 K 0.011

Local topological invariant of an interacting, time-reversal-symmetric Hofstadter interface — •Bernhard Irsigler, Jun-hui Zheng, and Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main

Two-dimensional topological insulators possess conducting edge states at their boundary while being insulating in the bulk. However, the detection of edge states remains an open question in ultracold atom setups. We propose a configuration to implement a topological interface within the experimentally realizable Hofstadter model which gives rise to a topological phase boundary at the center of the system, and investigate the influence of two-body interactions in a fermionic system. The location of the boundary can in principle be detected via the spatially resolved compressibility of the system with a quantum gas microscope. Furthermore, we compute a local topological invariant through adiabatic pumping which confirms the topological phase separation.

Q 19.3 Mon 16:45 K 0.011

Topological invariant for 2D open systems — •Jun-Hui Zheng and Walter Hofstetter — Goethe-Universität, 60438 Frankfurt am Main, Germany

We study the topology of 2D open systems in terms of the Green's function. The Ishikawa-Matsuyama formula for the integer topological invariant is applied in open systems and the equivalent descriptions through topological Hamiltonian and Berry curvature are developed separately. The invariant is well-defined iff all of the eigenvalues of the Green's function for imaginary frequency are finite nonzero numbers. Meanwhile, we define another topological invariant via the single particle density matrix, which works for general gapped systems and is equivalent to the former for the case of weak coupling to an environment. We also discuss two applications. For time-reversal invariant insulators, we explain the relation between the invariant for each spin-subsystem and the Z_2 index of the full system. As a second application, we consider the interference effect when an ordinary insulator is coupled to a topological insulator. The bulk-boundary correspondence of the open system shows new features.

Q 19.4 Mon 17:00 K 0.011

Topological phase transition in 2D interacting disordered systems — •Jun-Hui Zheng and Walter Hofstetter — Goethe-Universität, 60438 Frankfurt am Main, Germany

We study the topological phase transition and the transport properties in two-dimensional interacting disordered systems. A generalized Ishikawa-Matsuyama formula is developed as a topological index. Without considering the vertex correction of current operators, it corresponds to the Hall conductance of the system, within the dynamical mean-field approximation. As an example, we consider the spinful Haldane-Hubbard model. The averaged Hall conductance over different configurations of disorder is evaluated and the interaction effects are token into account by employing the dynamical mean-field theory. The finite size effects of the system are also discussed.

Q 19.5 Mon 17:15 K 0.011

Hidden order and symmetry protected topological states in quantum link ladders — •Lorenzo Cardarelli[1], Sebastian Greschner[2], and Luis Santos[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Department of Quantum Matter Physics, University of Geneva , 1211 Geneva, Switzerland

We show that whereas spin-1/2 one-dimensional U(1) quantum-link models (QLMs) are topologically trivial, when implemented in ladder-like lattices these models may present an intriguing ground-state phase diagram, which includes a symmetry protected topological (SPT) phase that may be readily revealed by analyzing long-range string spin correlations along the ladder legs. We propose a simple scheme for the realization of spin-1/2 U(1) QLMs based on single-component fermions loaded in an optical lattice with s- and p-bands, showing that the SPT phase may be experimentally realized by adiabatic preparation.

Q 20: Quantum Optics III

Time: Monday 16:15–17:45 Location: K 0.016

Q 20.1 Mon 16:15 K 0.016

Coupling Single Mode Fibers to Single Quantum Emitters with Femtosecond 3D Printing Technology — •Ksenia Weber[1], Simon Thiele[2], Simon Ristok[1], Mario Hentschel[1], Alois Herkommer[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institute for Applied Optics and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 9, 70569 Stuttgart, Germany

We propose a method to efficiently couple single photon quantum emitters to single optical mode fibers. Due to the undirected emission of single photon sources, such as quantum dots or defect centers in crystals, coupling into optical fibers which is essential for long range quantum communication is typically associated with high losses. To overcome this limitation, femtosecond two-photon lithography can be used to directly fabricate a combination of a microlens and an optical fiber chuck onto a quantum emitter. A single mode optical fiber is then integrated into the fiber holder. Due to the high precision of the femtosecond 3D printing process, the position of the fiber core can be adjusted with sub-micrometer accuracy to match the focal point of the microlens, as well as matching the high emission NA with the low input NA of the fiber. Light from the emitter which is focused by the microlens can therefore efficiently be coupled into the fiber.

Q 20.2 Mon 16:30 K 0.016

Emission properties and photon statistics of quantum-dot superluminescent diodes — •Franziska Friedrich and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt, Darmstadt, Germany

Broadband emitting quantum-dot superluminescent diodes (QD-SLDs) are indispensable semiconductor devices with many applications, e.g. in medical diagnostics (optical coherence tomography) or in fiber sensor technologies. Despite the widespread use, unusual behavior was observed regarding their photon statistics in a specific temperature regime [1]: the intensity correlation dropped down from 2 to 1.33 at $T = 190$K, which is relevant from a fundamental point of view.

Here, we present a microscopic theory of the amplified spontaneous emission (ASE) of a broadband QD-SLD with tilted end facets. This multimode quantum theory yields rate equations for the optical power densities, the level occupation of an inhomogeneous ensemble of quantum dots within the diode, as well as the emitted optical spectra. As a main result, we find the external power spectrum as a convolution of the intra-diode photon spectrum with a Lorentzian response, which agrees quantitatively with available experimental data [2]. In addition, we discuss photon statistics of QD-SLDs as a function of temperature.

[1] M. Blazek, W. Elsäßer, Phys. Rev. A **84**, 063840 (2011)
[2] F. Friedrich, R. Walser, to be published

Q 20.3 Mon 16:45 K 0.016

Temporal-mode selection with a quantum memory — •Benjamin Brecht[1], Sarah Thomas[1,2], Joseph Munns[1,2], Patrick Ledingham[1], Dylan Saunders[1], Joshua Nunn[3], and Ian Walmsley[1] — [1]Clarendon Laboratory, University of Oxford, Parks Road, Oxford, OX1 3PU, UK — [2]QOLS, Blackett Laboratory, Imperial College London, London SW7 2BW, UK — [3]Centre for Photonics and Photonic Materials, Department of Physics, University of Bath, North Road, Bath, BA2 7AY, UK

Photonic temporal modes (TMs) are appealing basis states for quantum information science. They are compatible with standard single-mode fibre, robust against linear dispersion, and span an infinite Hilbert space.

So far, TMs have been manipulated with dispersion-engineered frequency conversion processes, one example being the quantum pulse gate, where the selective conversion of one single TM to a different carrier frequency has been demonstrated.

Here we demonstrate TM selection with a quantum memory based on a two-photon Raman transition in warm atomic Caesium vapour. Contrary to frequency conversion, the memory does not necessarily change the carrier frequency of the selected mode, but rather separates TMs into different time bins. Also, the memory holds the potential to coherently re-shape the stored TM upon retrieval, making it a flexible tool for the manipulation of TMs at timescales that are not directly accessible with nonlinear optical processes.

Q 20.4 Mon 17:00 K 0.016

Non-classical states of light with smooth P-function — François Damanet[1,2], •Jonas Kübler[3], John Martin[2], and Daniel Braun[3] — [1]Department of Physics and SUPA, University of Strathclyde, Glasgow G4 0NG, United Kingdom — [2]Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, Université de Liège, Bâtiment B15, B - 4000 Liége, Belgium — [3]Institut für theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

In quantum optics, the most fundamental criterion to judge the non-classicality of a quantum state of light is in terms of the Glauber-Sudarshan P-function. If the P-function of a state is not a valid probability density, e.g. not a positive semi-definite function, the state is considered non-classical. However, most known non-classical states have a corresponding P-function which is highly irregular. This renders working with them difficult and direct experimental reconstruction impossible.

Here we introduce a new class of non-classical states with regular smooth P-functions by "puncturing" a classical P-function with narrow negative peaks. We analytically proof their existence and determine parameter ranges where the constructed states are physical, as well as the regimes yielding anti-bunching of light. To conclude, we present some possible experimental realizations of punctured states.

Q 20.5 Mon 17:15 K 0.016

Multimode photon-subtracted states of light — •Mattia Walschaers, Claude Fabre, Valentina Parigi, and Nicolas Treps — Laboratoire Kastler Brossel, UPMC-Sorbonne Université, ENS-PSL, Collège de France, CNRS, Paris, France

The deterministic generation of entanglement between large numbers of modes makes continuous variable quantum optics a promising platform for implementing quantum protocols. However, a genuine quantum advantage can only be achieved by introducing non-Gaussian features. Experimentally, this can be done through mode-tuneable photon subtraction.

In this contribution, we present a general theoretical framework to describe multimode photon subtracted states. With these theoretical tool we investigate a variety of non-Gaussian features in the state. In particular, we will focus on the newly introduced concept of inherent entanglement.

Q 20.6 Mon 17:30 K 0.016

Non-additivity of optical and Casimir-Polder potentials — •Sebastian Fuchs[1], Robert Bennett[1], Roman Krems[2], and Stefan Yoshi Buhmann[1] — [1]Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [2]University of British Columbia, Vancouver, Canada

An atom in presence of a surface experiences a usually attractive force caused by the fluctuations of the electromagnetic vacuum field, namely the Casimir-Polder (CP) force. On the other hand, an applied laser field causes an optical force on the atom. Using a perturbative approach, we report a new non-additive laser-induced CP potential stemming from the correlated coupling of the atom to both the laser field and the surface-assisted vacuum [1]. This term transforms the potential barrier of the two original potentials into a dip, that could serve as an atomic trap. Moreover, we outline an experimental setup to verify the occurence of this non-additive potential.

[1] Sebastian Fuchs, Robert Bennett, Roman V. Krems, and Stefan Yoshi Buhmann, arXiv:1711.10383 (2017)

Q 21: Optomechanics I

Time: Monday 16:15–17:45 Location: K 0.023

Q 21.1 Mon 16:15 K 0.023

Rotating ring resonators and Maxwell's equations in non-inertial frames — •Anton Lebedev — Institut für Theoretische Physik Tübingen, Tübingen

The majority of laws in physics is formally expressed in the form of (partial) differential equations (PDEs). Each differential equation remains incomplete without initial or boundary conditions.

Using Maxwell's equations and rotating planar domains I endeavour to highlight the intimate relationship between PDEs and boundary conditions. The necessity of the general covariant formulation of the laws of electrodynamics when dealing with accelerated motion will be highlighted. This will be used to derive of a Coriolis-Zeeman addendum to the wave equation for rotating ring resonators. All of the above will be done using the examples of isospectral domains and planar ring resonator models. Furthermore the use of the Coriolis-Zeeman term for a geometric classification of planar domains will be discussed.

Q 21.2 Mon 16:30 K 0.023

Quantum State Retrodiction in Gaussian Systems — •Jonas Lammers[1,2] and Klemens Hammerer[1,2] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Hannover

Open quantum systems whose environment is observed evolve according to stochastic master and Schrödinger equations. These predict the system state conditioned on past observations. We address the problem of verification of conditionally prepared states through *retrodiction*, i.e., the estimation of a state lying in the past. We apply the method to Gaussian states in linear systems, and compute the backwards evolution of their first and second moments. In particular, we consider an optomechanical oscillator coupled to a thermal bath.

Q 21.3 Mon 16:45 K 0.023

Designing light-mediated interactions between atoms and a mechanical oscillator — •Thomas Karg[1], Baptiste Gouraud[1], Klemens Hammerer[2], and Philipp Treutlein[1] — [1]Department of Physics, Universität Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — [2]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert Einstein Institute), Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

Hybrid systems in which a mechanical oscillator is coupled to atomic spins are promising for quantum control of mechanical motion, quantum sensing and signal transduction as well as the study of non-classicality in macroscopic objects.

In our experiment we use laser light to couple an atomic ensemble to an optomechanical system. In this context we explore interactions mediated by an optical mode to which both systems couple in a cascaded fashion. This approach is versatile because it allows to couple spatially separated systems in a variety of different schemes making use of light as a quantum resource. Moreover it is of fundamental interest to explore the limits as to whether light can effectively act like a spring, mediating Hamiltonian interaction between distant oscillators.

We will report on both experimental and theoretical work towards the implementation of such a quantum interface between a collective atomic spin and a membrane inside a cryogenic optical cavity. We address the challenges of reaching the quantum regime in this hybrid system and present a unified theory of light-mediated interactions.

Q 21.4 Mon 17:00 K 0.023

Rotational quantum revivals of nanoscale particles — •Birthe Papendell, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

Recent progress in the optical manipulation [1-4] of levitated nanoparticles as well as the prospect of ro-translational ground state cooling [5] open the door for quantum experiments with orientational coherences. We present a scheme for the observation of quantum revivals in the rotation state of a nanoparticle in high vacuum. To assess the feasibility of the setup the rotational quantum dynamics nanometer-sized double-walled carbon nanotubes is studied in presence of environmental decoherence.

[1] Kuhn et al., Nano Lett. 15, 5604 (2015)
[2] Hoang et al., Phys. Rev. Lett. 117, 123604 (2016)
[3] Kuhn et al., Optica 4, 356-360 (2017)
[4] Kuhn et al., Nat. Commun. 8, 1670 (2017)
[5] Stickler et al., Phys. Rev. A 94, 033818 (2016)

Q 21.5 Mon 17:15 K 0.023

Long-range optical trapping and binding of microparticles in hollow-core photonic crystal fibre — •Shangran Xie[1], Dmitry Bykov[1], Richard Zeltner[1], Gordon Wong[1], Tijmen Euser[2], and Philip Russell[1] — [1]Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058 Erlangen, Germany — [2]NanoPhotonics Centre, University of Cambridge, Cavendish Laboratory, CB3 0HE Cambridge, UK

Optically levitated micro- and nanoparticles offer a playground for investigating photon-phonon interactions over macroscopic distances. An optically tweezered particle at low gas pressure is isolated from the external environment resulting in very high mechanical Q-factor. Optical binding between arrays of trapped particles adds an additional dimension to the field of "levitated optomechanics", allowing access to the rich collective dynamics. Here we report long-range optical binding of multiple microparticles, mediated by intermodal scattering and interference inside the evacuated core of a hollow-core photonic crystal fibre (HC-PCF). Three polystyrene microparticles are stably bound together with an inter-particle distance of ~40 μm, or 50 times longer than the trapping wavelength. The bound-particle array can be translated over centimetre distances along the fibre. The collective mechanical modes of the bound-particle array could be observed under 6 mbar pressure. The measured inter-particle distance and mechanical eigen-frequencies are supported by an analytical formalism modelling the binding dynamics. HC-PCF offers a unique platform for investigating levitated collective optomechanics in a well-protected environment.

Q 21.6 Mon 17:30 K 0.023

Optomechanically coupled nanospike array on the endface of a fibre — •Zheqi Wang, Shangran Xie, Xin Jiang, and Philip Russell — Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany

Arrays of optically coupled mechanical oscillators are promising for exploring the light-controlled linear and nonlinear dynamics of complex systems. Here we report the fabrication and characterization of an optomechanically coupled glass nanospike array on the endface of a multi-core fibre. The multi-core fiber is made from soft glasses by the stack-and-draw technique, using two types of specially developed germanate glasses with widely different etch rates when subjected to a solution of nitric acid. Through wet-etching at one end of the fiber, an array of free-standing nanospikes can be obtained at the fiber endface. We have fabricated a fiber with a close-packed hexagonal array of seven cores of diameter 1.1 μm, the core centres being spaced 1.5 μm apart. After etching, the cladding material is removed, resulting in seven suspended conical nanospikes of length $\sim$20 μm. The diameter at the very end of the nanospikes is less than 50 nm. The optical mode in each step-index core spreads out adiabatically as it travels towards the tip, resulting in strong coupling between the individual nanospikes and significant optical forces that can be used to drive the mechanical motion of the nanospikes. The strength of the optomechanical interaction is estimated by numerical simulations and confirmed by preliminary experimental results. This unique system offers many new possibilities for exploring the behaviour and applications of optomechanical arrays.

Q 22: Matter Wave Optics II

Time: Monday 16:15–17:45 Location: K 1.013

Q 22.1 Mon 16:15 K 1.013

Testing Multi-path interference using molecule diffraction — •Christian Brand[1], Joseph Cotter[1], Christian Knobloch[1], Yigal Lilach[2], Ori Cheshnovsky[2], and Markus Arndt[1] — [1]Faculty of Physics, Boltzmanngasse 5, A-1090 Vienna, Austria — [2]Center for Nanoscience and Nanotechnology and School of Chemistry, Tel Aviv University, 69978 Tel Aviv, Israel

In quantum mechanics, the probability to measure a particle at a certain position is described by the square modulus of its wavefunction. This cornerstone of quantum-physics, known as Born's rule, underlies all quantum measurements, but is not immediately relevant for our classical world. In the search for a possible transition from quantum to classical phenomena, it has been proposed that the quantum mechanics may have non-linear extensions, giving rise to higher-order terms in multi-path interference [1]. This idea has been tested with mass-less photons with high accuracy [2]. Here, we present an explicit test of higher-order interference for the first time using massive organic molecules [3]. A thermal beam of phthalocyanine molecules was diffracted at a mask containing a combination of single-, double-, and triple-slits nanomachined into a 20 nm thin carbon membrane. From the analysis of the diffraction pattern in the matter-wave far-field, we deduce an upper bound for the possible contribution of higher-order interference for a wide region of molecular velocities of less than 1%.

[1] Sorkin, Mod. Phys. Lett. A **9**, 3119 (1994) [2] Urbasi, Science **329**, 418 (2010) [3] Cotter et al. Sci. Adv. **3**, 1607478 (2017)

Q 22.2 Mon 16:30 K 1.013

Polarization and mirror imperfections in retroreflective Raman– and Bragg diffraction — •Alexander Friedrich[1], Eric P. Glasbrenner[1], Enno Giese[2], Wolfgang P. Schleich[1], and Ernst M. Rasel[3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D–89069 Ulm. — [2]Department of Physics, University of Ottawa, K1N 6N5 Ottawa. — [3]Institut für Quantenoptik, Leibniz Universität Hannover, D–30167 Hannover.

Light–pulse atom interferometry has become a formidable tool for high precision applications in quantum sensing and tests of fundamental physics. Nowadays interferometers of this type rely on either Bragg– or Raman diffraction for the beamsplitting process. Retroreflective setups with two counterpropagating lattices reduce the effect of wave–front distortions and mirror vibrations. However, as the miniaturization of atom interferometers progresses, even imperfect mirrors such as the atom chip surface may serve as a retroreflection mirror in typical experiments. In our talk we introduce a model to quantify the influence of non–perfect polarization orientation and mirrors on the diffraction of a matter wave inside such a retroreflective geometry.

A.F. thanks the Center for Integrated Quantum Science and Technology (IQ^{ST}) and the QUANTUS collaboration for funding.

The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1556.

Q 22.3 Mon 16:45 K 1.013

Talbot-Lau interferometer for antimatter — •Andrea Demetrio[1], Simon R. Müller[1], Pierre Lansonneur[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut de Physique Nucléaire de Lyon, CNRS/IN2P3, 69622 Villeurbanne, France

The Talbot-Lau interferometer has been used to perform measurements in the near-field regime with several different particle species in the past two decades. In order to deal with divergent, low intensity sources, such as currently available for antimatter, a large geometrical acceptance is desirable. We discuss that this directly translates into very stringent limits on the alignment of its components, depending on the diffusivity of the beam. Furthermore, when considering charged particles, the influence of external electric and magnetic fields plays a role in degrading the fringe visibility, especially as the length of the device increases. We present a concrete application of these principles to an experimental test setup with protons and discuss the implications for antimatter experiments.

Q 22.4 Mon 17:00 K 1.013

Aberrations of Bragg beam splitters - 3D simulations — •Antje Neumann and Reinhold Walser — Institut Angewandte Physik, TU Darmstadt, Deutschland

Atomic beam splitters are a central component of matter wave interferometers, which provide the opportunity of high-precision rotation and acceleration sensing. Potential applications range from fundamental physics to inertial navigation. In the QUANTUS free-fall experiments atom interferometry is the central method as well.

Beam splitters are used to prepare coherent superposition of atomic wave packets in momentum space by transferring photon momentum from a laser field. Clearly the aim of such devices is to cover a wide momentum range with unit response. Equivalent to optical systems all matter wave devices require accurate specifications and ubiquitous imperfections need to be quantified.

We focus on the response and aberrations of an atomic beam splitter in quasi Bragg configuration in 3D. In particular, we characterize the non-ideal behaviour due to spatial variations of the laser beam profiles and wave front curvatures, regarding realistic Gaussian laser beams instead of ideal plane waves. In addition, different temporal envelopes of the laser beam will be considered. We present results of numerical and analytical studies of the velocity dependence of the complex reflectivity of the beam splitter. Finally our theoretical results are confirmed by experimental data [1].

[1] M. Gebbe, Universität Bremen, Zarm, private communication.

Q 22.5 Mon 17:15 K 1.013

Coherence measurements of multiphoton-photoemitted electrons from tungsten nano tips — •Stefan Meier, Takuya Higuchi, Philipp Weber, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Metal nanotips represent widely used coherent electron sources nowadays. By using them as dc field emission tips, an upper limit of their effective source size r_{eff} of only 0.4 nm was found [1]. This means that they show high spatial coherence properties, enabling matter-wave experiments, such as electron diffraction, holography or electron interferometry, as well as highest resolution electron microscopy. But electron emission from metal nanotips can also be triggered via photoemission. It was shown for tungsten nanotips that r_{eff} of electrons emitted in a single-photon emission process was almost as small as for dc field-emitted electrons under the same experimental conditions, so the supreme spatial coherence is maintained although the emission process is completely different [2]. By triggering the tips with femtosecond laser pulses it is possible to strongly confine the electron emission in time and therefore add high temporal resolution to these techniques. With the help of electron interference fringes after a CNT-based nanobiprism we here show results on characterizing the spatial coherence properties of electrons emitted via a nonlinear multiphoton photoemission process under illumination with few-cycle laser pulses.

[1] B. Cho *et al.*, Phys. Rev. Lett. **92**, 246103 (2004)

[2] D. Ehberger *et al.*, Phys. Rev. Lett. **114**, 227601 (2015)

Q 22.6 Mon 17:30 K 1.013

Quantum Limitation to the Coherent Emission of Accelerated Charges — •Alessandro Angioi and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

Accelerated charges emit electromagnetic radiation [1]. According to classical electrodynamics if the charges are sufficiently close to each other they emit coherently, i.e., their emission yield scales quadratically with the number of emitting charges rather than linearly. By investigating the emission by two-electron wave packets in the presence of an electromagnetic plane wave within strong-field QED [2], we show that quantum effects deteriorate the coherence predicted by classical electrodynamics even if the quantum nonlinearity parameter is much smaller than unity and classical and quantum results are expected to agree [3]. We explain this result by observing that coherence effects are also controlled by a new quantum parameter which relates the recoil undergone by the electron with the width of its wave packet in momentum space.

[1] J. D. Jackson, *Classical electrodynamics* (Wiley, New York, 1999).
[2] A. Di Piazza et al., *Rev. Mod. Phys.* **84**, 1177 (2012).
[3] A. Angioi and A. Di Piazza, *In preparation.*

Q 23: Precision Spectrosocopy III - trapped ions (joint session A/Q)

Time: Monday 16:15–17:45 Location: K 1.016

Invited Talk Q 23.1 Mon 16:15 K 1.016

Collinear Laser Spectroscopy for High Voltage Metrology at the 1 ppm accuracy level — •Jörg Krämer[1], Kristian König[1], Christopher Geppert[2], Phillip Imgram[1], Bernhard Maass[1], Johann Meisner[3], Ernst W. Otten[4], Stephan Passon[3], Tim Ratajczyk[1], Johannes Ullmann[5], and Wilfried Nörtershäuser[1] — [1]Institut für Kernphysik, Technische Universität Darmstadt — [2]Institut für Kernchemie, Johannes Gutenberg Universität Mainz — [3]Physikalisch-Technische Bundesanstalt, Braunschweig — [4]Institut für Physik, Johannes Gutenberg Universität Mainz — [5]Institut für Kernphysik, Westfälische Wilhelms-Universität Münster

Voltages of the order of a few Volts can be traced back to a Josephson standard that converts a microwave frequency to a voltage by inducing a current between two superconductors. However, high voltages cannot be traced back directly, but have to be divided down by precision high voltage dividers that reach a relative accuracy of 1 ppm at best.

Similar to the Josephson effect, collinear laser spectroscopy connects the laser frequency in the laboratory frame to the high voltage used to accelerate the ions via the Doppler shift. Since this frequency can be measured with 1 Hz precision using an optical frequency comb, this technique has the potential to reach an accuracy of <1 ppm.

We will present results of laser spectroscopic high voltage measurements using a pump and probe scheme on Ca ions at the 5 ppm level, and we will elaborate on how we plan to further decrease our uncertainties by using indium ions from a liquid metal ion source and an alternative pump and probe approach.

Q 23.2 Mon 16:45 K 1.016

Measuring the temperature and heating rate of a trapped single ion by imaging — •Bharath Srivathsan[1,2], Martin Fischer[1,2], Lucas Alber[1,2], Markus Weber[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2,3] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen - Nürnberg (FAU), Department of Physics, Erlangen, Germany — [3]Department of Physics, University of Ottawa, Canada

We present a technique to measure the temperature and the heating rate of a Doppler-cooled, single ion confined in a harmonic trap. In our experiment, we use a single $^{174}Yb^+$ ion trapped at the focus of a parabolic mirror covering almost 4π solid angle. The fluorescence light scattered by the ion from the cooling laser is imaged onto an EMCCD camera. We measure the size of this image while varying the power of the cooling laser. From this measurement data, we determine the heating rate by a fit to a well-known theoretical model for cooling in a trap [1]. Our method enables one to measure the heating rate directly at the Doppler limit, i.e. in a regime which is generally inaccessible to other common techniques.

[1] Stig Stenholm, Rev. Mod. Phys. 58, 699 (1986).

Q 23.3 Mon 17:00 K 1.016

Optical ion traps for investigation of atom-ion interactions — •Markus Debatin, Pascal Weckesser, Fabian Thielemann, Yannick Minet, Julian Schmidt, Leon Karpa, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs Universität Freiburg, Germany

We demonstrate optical trapping of $^{138}Ba^+$ ions in absence of any rf-confinement for durations of up to 3 seconds [1] as well as optical trapping of Coulomb crystals. With the trapping probability approaching unity for durations of 100 ms and with low heating, and electronic decoherence rates, our results establish optical ion trapping as a novel and robust tool for the manipulation of cold trapped ions, e.g. in atom-ion interaction experiments [2,3]. We give an update of our experiments, which combine the Ba^+ ion with bosonic ^{87}Rb and fermionic ^6Li atoms in order to explore ultracold interactions.

[1] A. Lambrecht et al., Nature Photonics **11.11** 704 (2017)
[2] see e.g.: A. Grier et al., PRL **102**, 223201 (2009)
[3] M. Tomza et al. *arXiv:1708.07832 (2017)

Q 23.4 Mon 17:15 K 1.016

Fock state interferometry: The single ion quantum pendulum — •Fabian Wolf[1], Chunyan Shi[1], Jan C. Heip[1], Manuel Gessner[2], Luca Pezzè[2], Augusto Smerzi[2], Marius Schulte[3], Klemens Hammerer[3], and Piet O. Schmidt[1,4] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]QSTAR, INO-CNR and LENS, Firenze, Italy — [3]Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz Universität, Hannover, Germany — [4]Institut für Quantenoptik, Leibniz Universität, Hannover, Germany

The motion of a single trapped ion constitutes a physical implementation of the quantum mechanical harmonic oscillator that is controllable on the single quantum level.

We demonstrate frequency and amplitude measurements of this "quantum pendulum" with sensitivities below what is achievable with its classical counterpart.

For this purpose we prepare the ion in motional Fock states. The non-classical features of these states provide metrological gain independent of the relative phase of the ion's oscillation with respect to the local oscillator, which is a major advantage over non-classical probing schemes based on squeezing or Schrödinger cat states and allows quantum-enhanced probing of two conjugate variables with the same state. We present a metrological analysis of our probing scheme based on the Fisher information and via an Allan-deviation analysis for both a trapping frequency and an oscillation amplitude measurement.

Q 23.5 Mon 17:30 K 1.016

Test of the isotropy of space with a high-precision long-term comparison of two single-ion optical clocks — •Richard Lange, Christian Sanner, Nils Huntemann, Burghard Lipphardt, Christian Tamm, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We employ two $^{171}Yb^+$ single-ion optical frequency standards that differ significantly with respect to trap geometry, control software and interrogation sequence. The clock frequency is determined by the $^2S_{1/2} \to {}^2F_{7/2}$ electric octupole (E3) transition. The relative systematic uncertainty of the clocks has been evaluated to less than 4×10^{-18} [PRL **108**, 090801 (2016)]. In a long-term comparison of the two clocks for a period of seven month with a duty cycle of up to 95 % per day, we found an agreement of the clock frequencies within the systematic uncertainty. Due to the electronic structure of the $^2F_{7/2}$ state, the E3 transition frequency is very sensitive to violations of Local Lorentz Invariance (LLI) [Nature Physics **12**, 465 (2016)]. In our experiment, this violation would manifest itself in a modulation of the clocks' frequency difference caused by the rotation of the earth in space. Analyzing our long-term data with millihertz resolution, we improve the current limits of violations of LLI in the electron sector by a factor of 100.

Q 24: Quantum Information (Solid State Systems)

Time: Monday 16:15–17:45 Location: K 1.020

Q 24.1 Mon 16:15 K 1.020

Scalable coupling of nearly lifetime-limited quantum emitters to diamond nanocavites — •Tim Schröder[1,2], Matt E. Trusheim[1], Michael Walsh[1], Sara Mouradian[1], Luozhou Li[1], Jiabao Zheng[1], Marco Schukraft[1], Mikkel Heuck[1], Alp Sipahigil[2], Ruffin E. Evans[3], Denis D. Sukachev[3], Christian T. Nguyen[3], Jose L. Pacheco[4], Ryan M. Camacho[4], Edward S. Bielejec[4], Mikhail Lukin[3], and Dirk Englund[1] — [1]RLE, Massachusetts Institute of Technology, USA — [2]Niels Bohr Institute, University of Copenhagen, Denmark — [3]Depart of Physics, Harvard University, USA — [4]Sandia National Laboratories, USA

Long-lived solid-state spin systems can serve as quantum memory in quantum information applications. Crucial for their integration in large-scale quantum architectures is their coupling to coherent photons. Here, we present the targeted creation of single silicon vacancy centres (SiV) with up to 25% conversion yield via Si focused ion beam implantation with <50 nm positioning accuracy relative to a nanocavity mode maximum. An inhomogeneously broadened ensemble linewidth of ∼51 GHz and close to lifetime-limited single-emitter transition linewidths are measured. Furthermore, targeted implantation of nitrogen vacancy (NV) centres into cavity mode maxima through self-aligned lithography enables an average of 1.1 ± 0.2 NVs per cavity with cavity-fed spectrally selective intensity enhancement of up to 93. [1] T. Schröder, M. E. Trusheim, M. Walsh et al., Nature Communications 8, 15376 (2017). [2] T. Schröder, M. Walsh, J. Zheng et al., Opt. Mater. Express, OME 7, 1514 (2017).

Q 24.2 Mon 16:30 K 1.020

Deterministische Einzel-Ionen Implantation zur Erzeugung von Seltene-Erden Farbzentren — •Karin Groot-Berning[1,2], Georg Jacob[2], Sebastian Wolf[2], Felix Stopp[2], Thomas Kornher[3], Roman Kolesov[3], Jörg Wrachtrup[3], Kilian Singer[1] und Ferdinand Schmidt-Kaler[2] — [1]Experimental Physik, Universität Kassel, Heinrich-Plett- Straße 40, 34132 Kassel, Germany — [2]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [3]3. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

Wir berichten über die erfolgreiche Erzeugung von ^{141}Pr-Farbzentren in Yttrium-Aluminium-Granat (YAG) mittels Implantation. Dazu nutzen wir eine lineare Paulfalle als deterministische Einzel-Ionenquelle. Zum Laden von Fremdatomen ist die Fallenapparatur zusätzlich mit einer komerziellen Ionenquelle ausgestattet. Mittels eines Nd:YAG Laserpulses bei 532 nm wird Praseodym von einem Metalltarget ablatiert und in der Ionenquelle durch Elektronenstoß ionisiert. Die Ionen werden auf 500 eV beschleunigt und in die Falle geschossen. Dort wird das $^{141}Pr^{+}$-Ion gefangen und durch ein $^{40}Ca^{+}$-Ion sympathetisch gekühlt. Mit einer Extraktionsspannung von 5.9 keV werden die $^{141}Pr^{+}$-Ionen aus der Falle beschleunigt, vom Calcium Ion getrennt und durch eine elektrostatische Einzellinse auf die Probe fokussiert [1]. Der gemessene Strahlradius beträgt für Praseodym 23.1 ± 7.7 nm. Wir weisen die gebildeten Zentren im YAG mittels eines *upconversion* Mikroskops nach.

[1] Jacob et al., Phys. Rev. Lett. 117, 043001 (2016)

Q 24.3 Mon 16:45 K 1.020

Thin vacancy as a novel candidate for quantum information processing — •Mathias H. Metsch[1], Petr Siyushev[1], Takayuki Iwasaki[2], Mutsuko Hatano[2], Shinobu Onoda[3], Junichi Isoya[4], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Germany — [2]Department of Electrical and Electronic Engineering, Tokyo Institute of Technology , Meguro, Tokyo 152 - 8552, Japan — [3]Takasaki Advanced Radiation Research Institute, National Institutes for Quantum and Radiological Science and Technology, 1233 Watanuki, Takasaki, Gunma 370-1292, Japan — [4]Research Centre for Knowledge Communities, University of Tsukuba, Tsukuba, Ibaraki 305-8550, Japan

The negatively charged thin vacancy (SnV) center in diamond is another color center formed by an impurity of the fourth group of chemical elements. Along with silicon and germanium it forms defect centers of D3d symmetry that show good optical properties in combination with a spin $\frac{1}{2}$ qubit. Due to the much larger ground state splitting undesirable phonon interaction is reduced at higher temperatures which should lead to longer electron spin coherence comparable with silicon vacancy at mK temperatures. The combination of a potentially long lived spin $\frac{1}{2}$ qubit with a bright and narrow optical transition turns the SnV into an interesting candidate light matter interface applications.

Q 24.4 Mon 17:00 K 1.020

Towards electrical detection of nearly single NV defects — •Petr Siyushev[1], Emilie Bourgeois[2], Fedor Jelezko[1], and Milos Nesladek[2] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Institute for Materials Research, Hasselt University, B-3590 Diepenbeek, Belgium

Over the last decade, nitrogen-vacancy (NV) center in diamond has become a prominent candidate for magnetic field sensing, nanoscale NMR, and quantum information processing. However, readout of measured signals is done optically. This requires bulky systems for detection and counting photons. Implementation of realistic devices would require miniaturization of the system and preferably integration of the system into single chip for simple compatibility with existing electronics. Substitution of traditional optical readout by its electrical analog would allow realization of diamond electronic chip. Recently, we demonstrated electrical detection of electron paramagnetic resonance on ensemble of NV centers [1] as well as electrical readout of electron spin state [2]. This method is based on detection of charge carriers which are promoted to the conduction band by two-photon excitation process of NV center [3]. Although, detection of a signal from a single NV is possible, this remains challenging due to strong background produced by other impurities. Here, we show electrical detection of nearly single NV defects.

[1] E. Bourgeois et al., Nat. Commun. **6**, 8577 (2015)
[2] M. Gulka et al., Phys. Rev. Applied **7**, 044032 (2017)
[3] P. Siyushev et al., Phys. Rev. Lett. **110**, 167402 (2013)

Q 24.5 Mon 17:15 K 1.020

Measurement controlled quantum state engineering of a spin environment — •Durga Dasari[1,2], Stefan Jesenski[1], Johannes Greiner[1], Florian Kaiser[1], Sen Yang[3], and Joerg Wrachtrup[1,2] — [1]University of Stuttgart, Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]The Chinese University of Hong Kong, Hong Kong

Quantum systems are inevitably coupled to their surrounding environment and are never completely isolated. Controlling such systems through measurements not only affects the system of interest but also its surroundings i.e, environment influences the measurement result and in turn the measurement influences the environment. This kind of back-to-back action adds new feature in steering the evolution of quantum baths through quantum measurements.

We explore this phenomena both theoretically and experimentally using solid state defect centers in diamond. Our studies indicate that there exists an optimal state of the environment which protects the coherence of the quantum system coupled to it and the statistics of the measurement results that lead to such engineered state follow Quantum Random Walk behavior. We will further show application of such measurement-controlled bath engineering towards machine learning and solving certain classical (NP-)hard problems.

Q 24.6 Mon 17:30 K 1.020

What it takes to shun equilibration — •Rodrigo Gallego[1], Henrik Wilming[1], Jens Eisert[1], and Christian Gogolin[2] — [1]Dahlem Center for Complex Quantum Systems, Freie Universitat Berlin, 14195 Berlin, Germany — [2]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

Numerous works have shown that under mild assumptions unitary dynamics inevitably leads to equilibration of physical expectation values if many energy eigenstates contribute to the initial state. Here, we consider systems driven by arbitrary time-dependent Hamiltonians as a protocol to prepare systems that do not equilibrate. We introduce a measure of the resilience against equilibration of such states and show, under natural assumptions, that in order to increase the resilience against equilibration of a given system, one needs to possess a resource system which itself has a large resilience. In this way, we establish a new link between the theory of equilibration and resource theories by quantifying the resilience against equilibration and the resources that are needed to produce it. We connect these findings with insights into local quantum quenches and investigate the (im-)possibility of formulating a second law of equilibration, by studying how resilience can be either only redistributed among subsystems, if these remain completely uncorrelated, or in turn created in a catalytic process if subsystems are allowed to build up some correlations.

Q 25: Quantum Gases (Fermions) I

Time: Monday 16:15–18:00 Location: K 1.022

Q 25.1 Mon 16:15 K 1.022

Probing homogeneous two-dimensional Fermi gases in momentum space — •Lennart Sobirey, Niclas Luick, Klaus Hueck, Fynn Förger, Jonas Siegl, Thomas Lompe, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Ultracold two-dimensional Fermi gases are uniquely suited to investigate the interplay of reduced dimensionality and strong interactions in quantum many-body systems. Here, we report on our realization of an ultracold 2D Fermi gas trapped in a homogeneous disk-shaped potential. This system is ideally suited to measure non-local quantities such as correlation functions and the momentum distribution. Furthermore, homogeneous systems simplify the creation of quantum phases which exist only in narrow regions of the phase diagram. To confine the homogeneous gas, we radially confine it by a ring-shaped blue-detuned beam with steep walls. We perform matter wave focusing to extract its momentum distribution and directly observe Pauli blocking in a near unity occupation of momentum states.

Q 25.2 Mon 16:30 K 1.022

Ground State of a Fermi Gas with Tilted Dipoles — •Vladimir Veljić[1], Aristeu R. P. Lima[2], Simon Baier[3], Lauriane Chomaz[3], Francesca Ferlaino[4,5], Axel Pelster[5], and Antun Balaž[1] — [1]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]University for International Integration of the Afro-Brazilian Lusophony, Brazil — [3]Institute for Experimental Physics, University of Innsbruck, Austria — [4]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Innsbruck, Austria — [5]Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Germany

In the presence of an anisotropic and long-range dipole-dipole interaction, the Fermi sphere of an ultracold Fermi gas deforms into an ellipsoid. Recently, it was experimentally observed in such systems that the shape of the Fermi surface follows the rotation of the dipoles when they are tilted [1]. Here we generalize the Hartree-Fock mean-field theory of Refs. [2, 3], where the dipoles were assumed to be parallel to one of the trap axes, to an arbitrary orientation of the dipoles and obtain the ground-state Thomas-Fermi radii and momenta. The calculated angular dependence of the Fermi surface deformation shows good agreement with experimental observations. We also find that the angular dependence of the aspect ratio turns out to be a direct consequence of the dipole tilting.

[1] K. Aikawa, et al., Science **345**, 1484 (2014).
[2] F. Wächtler, et al., Phys. Rev. A **96**, 043608 (2017).
[3] V. Veljić, et al., Phys. Rev. A **95**, 053635 (2017).

Q 25.3 Mon 16:45 K 1.022

High temperature pairing in a strongly interacting two-dimensional Fermi gas — •Luca Bayha[1], Puneet Murthy[1], Mathias Neidig[1], Ralf Klemt[1], Igor Boettcher[2], Tilman Enss[3], Marvin Holten[1], Gerhard Zürn[1], Philipp Preiss[1], and Selim Jochim[1] — [1]Physikalisches Institut, Universität Heidelberg — [2]Department of Physics, Simon Fraser University — [3]Institut für Theoretische Physik, Universität Heidelberg

Understanding the nature of the normal phase of strongly correlated Fermi systems is a fascinating open question in many-body physics.
In this talk I will present recent measurements, where we observe many-body pairing in a strongly interacting quasi two-dimensional ultracold Fermi gas at temperatures far above critical temperature for superfluidity. We employ spatially resolved radio-frequency spectroscopy to probe the pairing energy in the system. We identify and study a regime in the normal phase, where the pairing gap shows a clear density dependence and significantly exceeds the intrinsic two-body binding energy. This implies that pairing in this regime is driven by many-body correlations, rather than two-body physics. These correlations are remarkably robust against thermal fluctuations, as the effects persist up to temperatures close to the Fermi-temperature.

Q 25.4 Mon 17:00 K 1.022

Anomalous breaking of scale invariance in a two-dimensional Fermi gas — •Marvin Holten, Luca Bayha, Antonia Klein, Puneet Murthy, Philipp Preiss, and Selim Jochim — Physikalisches Institut, University of Heidelberg, Germany

The frequency of the breathing mode of a classical, two-dimensional Fermi gas in a harmonic confinement is fixed by the scale invariance of the Hamiltonian. On the quantum mechanical level, however, scale invariance is broken by introducing the two dimensional scattering length a_{2D} as a regulator. This is an example for a quantum anomaly in the field of ultracold atoms and leads to a shift of the frequency of the collective breathing mode of the cloud. In this talk, I present our experimental study of this frequency shift for a two component Fermi gas in the strongly interacting regime. We observe a significant shift away from the scale invariant result that depends on both interactions and temperature. A careful consideration of all the additional terms that may lead to explicit breaking of scale invariance is required to distinguish those from the effects caused by the anomaly.

Q 25.5 Mon 17:15 K 1.022

Violation of the Wiedemann-Franz law in a unitary Fermi gas — •Samuel Häusler, Dominik Husmann, Martin Lebrat, Philipp Fabritius, Laura Corman, Jean-Philippe Brantut, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zürich, Switzerland

In materials heat and particle transport are often coupled, leading to thermoelectric effects. A temperature gradient may cause particle transport (Seebeck effect) and a variation in chemical potential can induce heat currents (Peltier effect). These phenomena are suited to probe the fundamental excitations that are challenging to identify in strongly correlated matter.

To study these phenomena, we prepare a system consisting of two reservoirs of fermionic lithium atoms at unitarity close to the superfluid transition. After heating one of the reservoirs they may exchange particles and heat through a quantum point contact. We observe a violent initial particle current from cold to hot that brings the system to a non-equilibrium steady state where currents vanish in the presence of finite temperature difference and chemical potential bias. The steady state reveals a finite particle and suppressed thermal conductance strongly violating the Wiedemann-Franz law, which relates the two conductances by a universal number in the limit of low temperatures. This violation signals a breakdown of Fermi liquid behaviour and remains for wider channel geometries, where the system relaxes back to equilibrium. These findings are related to the celebrated fountain effect in bosonic helium II.

Q 25.6 Mon 17:30 K 1.022

Observation of the Higgs mode in the superfluid BEC-BCS crossover in Fermi gases — •Johannes Kombe, Jean-Sébastien Bernier, and Corinna Kollath — Uni Bonn, Nussallee 14-16, 53115 Bonn

Thanks to recent advances, investigating the non-equilibrium dynamics of interacting systems is now possible. Using time-dependent perturbations, one can probe from a different angle the mechanisms responsible for the collective phenomena present in correlated systems. Taking advantage of this progress, we investigate both theoretically and experimentally the evolution of a three-dimensional Fermi gas while the interaction strength is effectively modified. Our study, carried out on the BCS side, reveals various collective excitations. Interestingly, this approach highlights the presence of the Higgs mode.

Q 25.7 Mon 17:45 K 1.022

Spinor Gases of Fermionic Erbium Atoms — •Jan Hen-

drik Becher[1,3], Simon Baier[1], Lauriane Chomaz[1,2], Gabriele Natale[1], Daniel Petter[1], Manfred Mark[1,2], and Francesca Ferlaino[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria — [3]Physikalisches Institut, Heidelberg University, Germany

Over the last decade, dipolar quantum gases have become an ideal system to study novel phenomena in ultracold quantum physics. In particular, strongly magnetic atomic species, such as erbium, open fascinating possibilities to investigate dipole-dipole interaction (DDI) and its impact on few- and many-body effects in ultracold spinor gases.

Here we report on first experimental investigations of spin physics in fermionic erbium, ^{167}Er. Due to its large quantum numbers, fermionic erbium has a remarkably large number of spin states in the lowest level manifold, $F = 19/2$. The 20 different m_F states interact via both contact and DDI. The DDI is violating spin conservation and effects the dynamics of out-of-equilibrium spin systems.

In the experiment, we create a spin polarized, degenerate Fermi gas in the absolute lowest Zeeman sublevel. We then load the atomic sample into a 3D optical lattice and start spin preparation by applying a radio frequency pulse. In this setting, we study the interaction in the proximity of homonuclear p-wave Feshbach resonances and discover new interspin Feshbach resonances. Furthermore we investigate the dynamics of spin excitations in the frozen-particle regime.

Q 26: Ultracold Plasmas and Rydberg Systems II (joint session Q/A)

Time: Monday 16:15–17:30 Location: K 2.013

Q 26.1 Mon 16:15 K 2.013

Metastable decoherence-free subspaces and electromagnetically induced transparency in interacting many-body systems — •Katarzyna Macieszczak[1,2], YanLi Zhou[3], Sebastian Hofferberth[4], Juan P. Garrahan[1,2], Weibin Li[1,2], and Igor Lesanovsky[1,2] — [1]School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, United Kingdom — [3]College of Science, National University of Defense Technology, Changsha 410073, China — [4]Department of Physics, Chemistry and Pharmacy, University of Southern Denmark, Odense, Denmark

We investigate the dynamics of a generic interacting many-body system under conditions of electromagnetically induced transparency (EIT). This problem is of current relevance due to its connection to nonlinear optical media realised by Rydberg atoms. In an interacting system the structure of the dynamics and the approach to stationarity become far more complex than in the case of conventional EIT as a metastable decoherence-free subspace emerges, whose dimension for a single Rydberg excitation grows linearly in the number of atoms. We discuss the effective slow nonequilibrium dynamics, which features coherent and dissipative two-body interactions, and renders the typical assumption of fast relaxation invalid. We also show how this scenario can be utilised for the preparation of collective entangled dark states and the realisation of general unitary dynamics within the spin-wave subspace.

Q 26.2 Mon 16:30 K 2.013

Realization of a XXZ-model using Rydberg atoms — •Renato Ferracini Alves[1], Miguel Ferreira Cao[1], Titus Franz[1], Martin Gärttner[2], Asier Piñeiro Orioli[3], Andre Salzinger[1], Adrien Signoles[1], Nithiwadee Thaicharoen[1], Shannon Whitlock[1,4], Gerhard Zürn[1], Jürgen Berges[3,5], and Matthias Weidemüller[1,6] — [1]Physikalisches Institut, Universität Heidelberg, Germany — [2]Kirchhoff-Institut für Physik, Universität Heidelberg, Germany — [3]Institut für Theoretische Physik, Universität Heidelberg, Germany — [4]IPCMS and ISIS, University of Strasbourg and CNRS, Strasbourg, France — [5]ExtreMe Matter Institute EMMI, Darmstadt, Germany — [6]Shanghai Branch, University of Science and Technology of China, Shanghai, China

Cold Rydberg gases are a suitable platform for studying quantum many body dynamics, due to its strong and long range interactions. Questions regarding thermalization in closed quantum systems and relaxation dynamics after a quench can be addressed experimentally. This project investigates the many body dynamics of a few thousand disordered Rydberg atoms. In particular we realize a Heisenberg XXZ spin model by mapping two interacting Rydberg states to an effective spin 1/2 system. Coupling these states with a phase-controlled microwave radiation, allows us to perform arbitrary global initial state-preparation and, together with state selective ionization, a state-tomographic detection. With these techniques we extract the magnetization and study its time evolution. In this talk we will focus on recent measurements of the spin dynamics after a quench.

Q 26.3 Mon 16:45 K 2.013

Quasi-particle spectra of bosonic Rydberg-dressed many-body phases — •Andreas Geissler[1], Yongqiang Li[2], Weibin Li[3], Ulf Bissbort[4], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Johann Woalfgang Goethe-Universität, Frankfurt/Main — [2]Department of Physics, National University of Defense Technology, Changsha, China — [3]School of Physics and Astronomy, University of Nottingham — [4]SUTD, Singapore

As recent experiments have demonstrated the feasibility of Rydberg dressing [1], even in a lattice system [2], the stage is set for realizing (long predicted) exotic states of matter in ultracold gases. Our latest results (simulated in real-space bosonic dynamical mean-field theory RB-DMFT) have shown a rich diversity of crystalline and supersolid quantum phases, both close to resonant driving [3] and in the weak dressing limit [4]. While in the former case we predict a reduction of the Rydberg fraction compared to single atom dressing, we show in the latter case how a two-species mixture can make the realization of a supersolid more accessible. Based on these results we applied a quasi-particle method based on linearized Gutzwiller dynamics (Gqp), to predict various spectral functions for both cases and in an experimentally feasible regime. As RB-DMFT also predicts spectral properties, it serves as a benchmark for Gqp. We furthermore characterize the various observed gapped and ungapped quasi-particle modes.

[1] Y.-Y. Jau et al., Nat. Phys. 12, 71-74 (2016) [2] J. Zeiher et al., Nat. Phys. 12, 1095-1099 (2016) [3] A. Geißler et al., Phys. Rev. A 95, 063608 (2017) [4] Y. Li et al., arXiv:1705.01026

Q 26.4 Mon 17:00 K 2.013

Localisation dynamics in a disordered Rydberg ladder — •Maike Ostmann[1,2], Jiri Minar[1,2], Matteo Marcuzzi[1,2], and Igor Lesanovsky[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham

Rydberg lattice systems are currently studied in a number of laboratories worldwide as they constitute a promising platform for quantum information processing and the quantum simulation of many-body systems out of equilibrium. We are studying the transport of excitations in Rydberg systems under the so-called facilitation condition, where the excitation of an atom to a Rydberg state is strongly enhanced by an excited neighbour. In particular we are interested in understanding the impact of disorder caused by the uncertainty of the atomic positions within the individual lattice sites. In a recent work, a connection between localisation in real space and configuration (Fock) space was established. Building on this, we are investigating the localisation phenomena in a Rydberg ladder forming a so-called Lieb lattice in configuration space. A Lieb lattice supports a macroscopically degenerate flat band which gives rise to localised eigenstates in the absence of disorder. We are exploring the influence of the disorder on these localised eigenstates. Introducing disorder to our system leads to a non-monotonic behaviour of the localisation as a function of the interaction strength. Furthermore, we are studying how different types of disorder effect the scaling of the localisation length.

Q 26.5 Mon 17:15 K 2.013

Self-consistent theory of energy diffusion in ultracold Rydberg gases — •Katharina Hess, Andreas Buchleitner, and Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Herman-Herder-Straße 3, 79104 Freiburg, Deutschland

Due to their high degree of controllability, gases of ultracold Rydberg atoms are a good testbed to study fundamental questions of transport in spatially disordered quantum networks. In this talk, we will examine the transfer of a single Rydberg excitation mediated by coherent dipole-dipole interactions. We show that the dipole blockade effect can be used to change the character of transport from subdiffusive to diffusive [1]. In the latter case, we apply a self-consistent diagrammatic approach [2] in order to determine the value of the diffusion constant.

[1] T. Scholak, T. Wellens and A. Buchleitner, Phys. Rev. A 90, 063415 (2014)

[2] T. Wellens and R. A. Jalabert, Phys. Rev. B 94, 144209 (2016)

Q 27: Quantum Gases (Bosons) III

Time: Monday 16:15–17:45 Location: K 2.020

Q 27.1 Mon 16:15 K 2.020

Dimensional Crossover in a Bosonic Quantum Gas — •Polina Matveeva, Denis Morath, Dominik Strassel, Axel Pelster, Imke Schneider, and Sebastian Eggert — Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

From the Mermin-Wagner theorem it follows that there is no Bose-condensation in 1D at any finite temperature. Therefore one can ask the question about new critical exponents, that emerge when the 1D-3D crossover is studied in context of 3D anisotropic bosons on a lattice. Our model is represented by 1D tubes with hopping between them, which can be simulated in experiments with optical lattices [1]. Tuning the hopping between the tubes allows us to drive our system continuously from 1D to 3D. Here we determine the exponent, that appears for T_c, when it increases from zero as a function of inter-chain hopping [2]. To this end we use an effective potential approach to calculate the Landau potential and to derive critical parameters of the system as a function of inter-chain hopping, which we take into account perturbatively. We perform calculations both for non-interacting bosons in tubes and also for interacting bosons with infinite on-site repulsion and nearest neighbor density-density interaction. In the latter case these interactions are taken into account using the bosonization technique. We also compare our results with numerical results for the critical exponent, obtained from extensive Quantum Monte-Carlo simulations.

[1] A. Vogler et al., Phys. Rev. Lett. **113**, 215301 (2014)

[2] B. Irsigler and A. Pelster, Phys. Rev. A **95**, 043610 (2017)

Q 27.2 Mon 16:30 K 2.020

Finite size effects and scrambling at the quantum phase transition of a 1D Bose gas — •Benjamin Geiger, Quirin Hummel, Juan Diego Urbina, and Klaus Richter — Institut für theoretische Physik, Universität Regensburg, Germany

It is known from mean-field theory that a system of bosons with attractive contact interactions in one dimension exhibits a quantum phase transition at a certain critical coupling [1]. At this critical point the Bogoliubov spectrum collapses to a single point and thus mean-field theory fails to describe the characteristical finite level spacing. We investigate the situation for a large but finite number of particles in a momentum-truncated model and show that semiclassical many-body torus quantization allows to calculate the precursors of the quantum phase transition. We show that the phase transition is accompanied by a change in the topology of the available classical phase space, a fact that enables us to define a sharp critical coupling wherever the topology of a quantized torus changes, despite the fact that the spectrum is analytic in the interaction parameter. Our approach has a direct application to the description of scrambling times around criticality, a subject of large recent interest.

[1] R. Kanamoto, H. Saito, M. Ueda, Phys. Rev. A **67**, 013608 (2003)

Q 27.3 Mon 16:45 K 2.020

Multifractal properties of the ground state of the Bose-Hubbard model — •Jakob Lindinger, Andreas Buchleitner, and Alberto Rodriguez — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany

We study the multifractal properties of the ground state of the one-dimensional Bose-Hubbard model in Fock space. We confirm that the limit of vanishing interaction exhibits non-trivial multifractality in the Fock basis [1]. In order to get access to the multifractal properties at arbitrary values of the interaction strength, we use exact diagonalisation and quantum Monte Carlo simulations (which enable us to reach $L = 30$ in certain cases, corresponding to a Hilbert space of size $\mathcal{N} \approx 6 \times 10^{16}$). Our results suggest the existence of non-trivial multifractality in the ground state for a large range of interaction values. We find that an analysis of the generalised fractal dimensions for different densities exposes qualitatively the superfluid to Mott insulator transition. We furthermore explore different methods to quantitatively characterise the transition.

[1] E. Bogomolny. Multifractality in simple systems. Presentation at the conference “Complex patterns in wave functions: drums, graphs, and disorder” at the Kavli Royal Society Centre, UK. 2012

Q 27.4 Mon 17:00 K 2.020

Bottom-up approach to many-body physics with ultracold atoms in adjustable lattices — •Martin Sturm, Malte Schlosser, Gerhard Birkl, and Reinhold Walser — Institute for applied physics, TU Darmstadt, Darmstadt, Germany

Ultracold atoms in optical lattices have proven to be a powerful toolbox for quantum simulation of many-body physics. With the demonstration of single-site resolved imaging, local properties have shifted into the focus of this field. This development is complemented by the construction of double-well systems from single atoms in optical tweezers.

We present an experimental avenue to scalable and adjustable arrays of optical dipole traps using microlens arrays and spatial light modulators [1]. This setup closes the gap between the aforementioned approaches and allows for a bottom-up construction of many-body systems adding one atom at a time. In order to evaluate the experimental feasibility of this approach, we compute the accessible parameter regime for ^{7}Li, ^{23}Na, ^{41}K, and ^{87}Rb based on measurements and simulations of the light field. In addition, we investigate loading procedures starting from Bose-Einstein condensates as well as from low-entropy states in the deep Mott-insulator regime [2]. As a possible application, we analyze two coupled ring lattices that exhibit many-body resonances in their tunneling dynamics.

[1] M. R. Sturm et al., Phys. Rev. A **95** 063625 (2017)

[2] M. R. Sturm et al., to be published.

Q 27.5 Mon 17:15 K 2.020

Statistically Induced Phase Transition in the Extended Anyon-Hubbard Model — •Kevin Jägering, Shijie Hu, Martin Bonkhoff, Imke Schneider, Axel Pelster, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

We investigate the impact of non-trivial exchange statistics on bosonic SPT (symmetry protected topological) phases in one-dimensional optical lattices. As the underlying model we study the anyonic version of the extended Bose-Hubbard Hamiltonian with a generalized Pauli exclusion principle, restricting the maximal occupation up to two particles per site. Combining numerical DMRG techniques and a Gutzwiller Mean-Field treatment, we present the phase diagram of the system for different values of the statistical parameter. Additionally we employ bosonization to derive a low-energy field theory in order to describe the universal behaviour of the system near the critical points, and analyze the mechanism behind statistically induced phase transitions present in the system.

Q 27.6 Mon 17:30 K 2.020

Current reversals and metastable states in the infinite Bose-Hubbard chain with local particle loss — •Maximilian Kiefer-Emmanouilidis[1,2] and Jesko Sirker[2] — [1]Technische Universität Kaiserslautern, Kaiserslautern, Germany — [2]University of Manitoba, Winnipeg, Canada

Many-body interactions lead to unexpected effects in the open Bose-Hubbard model. When the model is subjected to local loss, particle currents are induced. Away from the dissipative site the currents start to reverse their direction at intermediate and long times. This leads to a metastable state with a total particle current pointing away from the dissipative site. We studied the model numerically by combining a quantum trajectory approach with a density-matrix renormalization group scheme. An alternative equation of motion approach based on an effective fermion model shows that the reversal of currents can be understood qualitatively by the creation of holon-doublon pairs at the edge of the region of reduced particle density. The doublons are then able to escape while the holes move towards the dissipative site.

Q 28: Cold atoms V - optical lattices (joint session A/Q)

Time: Tuesday 14:00–15:30 Location: K 0.011

Q 28.1 Tue 14:00 K 0.011

Two- and four-body spin-exchange interactions in optical lattices — •Bing Yang[1,2], Han-ning Dai[1,2], Andreas Reingruber[1], Hui Sun[1,2], Yu-ao Chen[2], Zhen-Sheng Yuan[2,1], and Jian-Wei Pan[2,1] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

Ultracold atoms in optical lattices represent an ideal platform for modeling elementary spin interactions. Here we report on the observations of two- and four-body spin-exchange interactions in an optical superlattice. Using a spin-dependent superlattice, atomic spins can be coherently addressed and manipulated. Bell states are generated via spin superexchange process and their quantum correlations are detected. A minimum toric code Hamiltonian in which the four-body ring-exchange interaction is the dominant term, is implemented by engineering a Hubbard Hamiltonian in disconnected plaquette arrays. Our work represents an essential step towards studying topological matters with many-body systems and the applications in quantum computation and simulation.

Q 28.2 Tue 14:15 K 0.011

Multimode Bose-Hubbard model for quantum dipolar gases in confined geometries — Florian Cartarius[1], •Rebecca Kraus[1], Ferdinand Tschirsich[2], Simone Montangero[1,2], Anna Minguzzi[3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Institute for Complex Quantum systems, Universität Ulm, D-89069 Ulm, Germany — [3]Université Grenoble-Alpes, CNRS, Laboratoire de Physique et Modélisation des Milieux Condensés, F-38000 Grenoble, France

We theoretically consider ultracold polar bosonic molecules in a wave guide. The particles experience a periodic potential due to an optical lattice oriented along the wave guide and are polarized by an electric field orthogonal to the guide axis. The array is mechanically unstable by opening the transverse confinement in the direction orthogonal to the polarizing electric field and can undergo a transition to a double-chain (zigzag) structure. For this geometry we derive a multimode generalized Bose-Hubbard model for determining the quantum phases of the gas at the mechanical instability, taking into account the quantum fluctuations in all directions of space. We determine the phase diagrams using exact diagonalization and an imaginary time-evolving block decimation program, where we also investigate the emergence of a Haldane insulating phase. We find that, even for tight transverse confinement, the aspect ratio between the two transverse trap frequencies controls not only the classical but also the quantum properties of the ground state in a nontrivial way.

Q 28.3 Tue 14:30 K 0.011

Ground state cooling of Cs atoms in state-dependent optical lattices — •Richard Winkelmann, Gautam Ramol, Stefan Brakhane, Goel Moon, Peng Du, Max Werninghaus, Wolgang Alt, Dieter Meschede, and Andrea Alberti — Institute of Applied Physics, Bonn, Germany

We report on experimental realization of ground state cooling of neutral Cs atoms in state dependent optical lattices, which are realized by fast optical polarization synthesis [1]. Two-dimensional polarization-synthesized optical lattices allow us to employ microwave radiation to couple different motional states in both x- and y-directions; by driving microwave sideband transitions, we succeed to cool atoms into the motional ground state in the xy-plane. A pair of Raman lasers is used to cool atoms in the third dimension, along which atoms are convined by a state-independent optical lattice. We expect to prepare >99% population in the ground state population for each dimension.

Ground state cooling enables both long coherence times and indistinguishability of atoms, which are prerequisites for discrete time quantum walks, the preparation low entropy states via atom sorting [2] and direct measurement of the exchange phase for identical quantum particles [3].

[1] C. Robens et al.,Fast, high-precision optical polarization synthesizer for ultracold-atom experiments., arXiv, 2017. [2] C. Robens et al., Low-entropy states of neutral atoms in polarization-synthesized optical lattices. PRL, 2017. [3] C. F. Roos et al., Revealing quantum statistics with a pair of distant atoms. PRL, 2017.

Q 28.4 Tue 14:45 K 0.011

Coupling a finite thermal bath to a many-body localized system — •Antonio Rubio-Abadal[1], Jae-yoon Choi[1], Johannes Zeiher[1], Simon Hollerith[1], Jun Rui[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München,

The thermalization of an isolated quantum system can fail in the presence of quenched disorder, even with interactions. This phenomenon, known as many-body localization (MBL), has been recently the focus of much theoretical work, though many open questions still remain regarding its existence in higher dimensions or its robustness to a finite bath coupling. Ultracold atoms in optical lattices have emerged as an extremely suitable platform for the study of MBL, and promise to shed light into some of its properties.

In our experiment, we use a quantum-gas microscope with projected disorder to study the dynamics of a quenched state of bosons in two dimensions, where we observe a remaining memory of the initially prepared state by measuring the evolution of its imbalance. By introducing a second bosonic species unaffected by the disorder potential, a thermal component has been added to the system, and we have measured its effect on the disordered component, which in the presence of a big enough thermal component ultimately loses its imbalance.

Q 28.5 Tue 15:00 K 0.011

Exploring the doped Fermi-Hubbard model in low dimensions — •Joannis Koepsell[1], Guillaume Salomon[1], Timon Hilker[1], Jayadev Vijayan[1], Michael Höse[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Fakultät für Physik, Ludwig-Maximilians-Univsersität, München

We use ultracold fermionic lithium atoms to realize synthetic one dimensional Fermi-Hubbard chains. With our quantum gas microscope we study emerging antiferromagnetic correlations as a function of doping and magnetization. The local spin and density resolution allows us to observe the change of the wave vector of the spin correlations as a function of density and magnetization. In a quantitative comparison we show that our results can be well described by Luttinger-liquid theory. Finally we report on ongoing studies of the system in the crossover from one to two dimensions.

Q 28.6 Tue 15:15 K 0.011

Progress in the cooling of molecules using a magnetic decelerator — Yair Segev, Michael Karpov, •Martin Pitzer, Nitzan Akerman, Julia Narevicius, and Edvardas Narevicius — Department of Chemical & Biological Physics, Weizmann Institute of Science, Rehovot, Israel

Ultracold and dense ensembles of molecules can complement their atomic counterparts in the investigation of various fundamental questions, e.g. in cold chemistry, precision measurements or many-body physics [1].

However, many cooling schemes - especially optical cooling - are much more difficult to implement for molecules than they are for atoms.

We report here our recent progress in a different approach, a magnetic decelerator for paramagnetic species [2,3].

A pulsed supersonic expansion provides a cold (around 300 mK) and extremely dense jet of oxygen molecules that are slowed down by a co-moving magnetic trap. After catching these molecules in a superconducting magnetic trap, several cooling schemes such as evaporative or sympathetic cooling can be performed. Due to the high initial particle density of 10^{10}cm^{-3}, we expect to observe collisions of molecules in the rovibrational ground state and study the elastic and inelastic cross sections relevant for cooling towards quantum degeneracy.

[1] Carr, et al., New J. Phys. 11, 055049 (2009)
[2] Akerman, et al., New J. Phys. 17, 065015 (2015)
[3] Akerman, et al., Phys. Rev. Lett. 119, 073204 (2017)

Q 29: Quantum Optics and Photonics I

Time: Tuesday 14:00–16:00 Location: K 0.016

Q 29.1 Tue 14:00 K 0.016

From electromagnetically induced transparency to Autler-Townes splitting with x-rays — •Xiangjin Kong[1], Jörg Evers[1], Johann Haber[2], Ralf Röhlsberger[2], and Adriana Pálffy[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Coherent control of light interacting with matter is one of the ultimate goals of optics and quantum physics. The key role is played by resonant interactions, with control often refined within a resonance by the use of a second field coupling to neighboring levels of a multi-level system. This can lead for instance via Fano interference effects to electromagnetically induced transparency (EIT)- the medium is rendered transparent over a narrow spectral window within an absorption line. A different route can be achieved via Autler-Townes splitting (ATS), where a single resonance line is replaced by a doublet structure in the absorption profile by pumping with a strong second field.

Here we investigate the transition between EIT and ATS in the x-ray regime using thin-film x-ray cavities with two layers of resonant nuclei. In such planar cavities, the incidence angle can be used as tunable parameter to observe either of the two processes [1,2]. We use the Akaike Information Criterion [3] to evaluate the experimental data and discern which of the two mechanisms is dominant. Our results confirm the observation of EIT and ATS in thin-film x-ray cavities.

[1] R. Röhlsberger *et al.*, Nature 482, 199 (2012).
[2] J. Haber *et al.*, Nature Photonics 11, 720 (2017).
[3] P. Anisimov *et al.*, Phys. Rev. Lett. 107, 163604 (2011).

Q 29.2 Tue 14:15 K 0.016

Stationary Collective Effects in Polarized Atomic Ensembles induced by off-resonant Probes — •Alexander Roth[1], Kirill Tikhonov[2], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics, Leibniz University Hannover — [2]St. Petersburg State University

We investigate atomic ensembles at room temperature with continuous optical pumping and off-resonant probing, which have previously been used in entanglement generation [1] and quantum back action evasion [2]. We show that the off-resonant probe acting collectively on all atoms induces atom-atom correlations leading to a superradiant behavior in the steady state. These collective effects can be tuned via the angle of linear polarization of the probe and influence relevant parameters such as the polarization and line-width significantly. Our numerical calculations with approximately 10^9 atoms use a new approach to the cumulant expansion allowing us to calculate higher correlation orders, such as the 8-atom cumulant. This new approach applies to a wide class of symmetric master equations and gives access to the reduced density matrix containing multi-atom correlations.

[1] Phys. Rev. Lett. 107, 080503 (2011)
[2] Nature 547, 191-195 (13 July 2017)

Q 29.3 Tue 14:30 K 0.016

Subradiant states in many-body quantum systems for excitation storage — •Jemma Needham[1,2] and Beatriz Olmos[1,2] — [1]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, University Park, Nottingham, NG7 2RD, UK. — [2]School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD, UK.

Many-body quantum systems are currently of great interest due to increased developments in quantum computation. We explore the dynamics associated with a 1D chain of atoms excited to low-lying states, limited to a single excitation within the system. The atoms are closely spaced such that the system enters a regime exhibiting collective behaviour. In particular, we are interested in the subradiant state that arises when an atomic chain is initialised with a single excitation at one end and then allowed to evolve. Subradiant states decay very slowly, if at all, and hence this system could find applications as a quantum memory. We derive expressions for long-range coupling between pairs of atoms and collective dissipation that occur due to small atomic spacing. We then develop a protocol to initialise an excited state, and we store the excitation for timescales much longer than those occurring naturally. This protocol allows natural evolution from a relatively simple initial state, into a slowly decaying state which could be utilised in the storage of quantum information. We finally explore the properties of the possible stored states, and gain further understanding on the system's time evolution.

Q 29.4 Tue 14:45 K 0.016

Superlattices by twisted bilayer photonic graphene in photorefractive media — •Matthias Rüschenbaum, Marius Rimmler, Alessandro Zannotti, and Cornelia Denz — Institut für Angewandte Physik and Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Photonic graphene, characterized by a hexagonal, periodic refractive index modulation, features outstanding light propagation, band structures, and topological effects. From solid state physics it is well-known that two rotationally mismatched graphene monolayers introduce an additional large scale periodicity and thus create graphene superlattices. Such a material leads to the appearance of new physical phenomena that manifests predominantly in its band structure. Especially, the new superlattice potential leads to the formation of Dirac points that are slightly displaced from the Fermi energy. Despite these attractive features, a photonic realization of superlattice graphene is still lacking.

In our contribution, we propose the realization of twisted bilayer photonic graphene superlattices by photo-induced refractive index changes. Our approach is based on reversible two-dimensional photonic lattices created by optical induction, using complex non-diffracting writing beams. The resulting lattices show a transversely modulated refractive index while being invariant in the direction of propagation. Incoherent superposition of two of this lattices enables the realization of superlattice structures providing a platform to optically investigate quantum mechanical and topological effects caused by twisted bilayer graphene.

Q 29.5 Tue 15:00 K 0.016

Solitons and their eigenvalues in the presence of gain and loss. — •Christoph Mahnke, Alexander Hause, and Fedor Mitschke — Universität Rostock, Institut für Physik, Albert-Einstein-Str. 23-24, 18059 Rostock, Germany

Due to the growing demand for data transmission capacity, the concept of fiber-optical solitons as information carriers [1] has regained interest recently [2]. This technique is based on soliton eigenvalues, which are invariants of the Nonlinear Schrödinger equation.

When one considers real-world implementations, power loss is unavoidable and amplification becomes a necessity. Then, the invariance of the soliton eigenvalues is lost. In this case researchers resorted to perturbation techniques [3]. Using the Nonlinear Fourier transform we can characterize solitons in the regime beyond weak gain or loss.

Considering the cases where the initial condition contains zero, one, or two solitons, we can demonstrate that the eigenvalue spectrum, and the soliton number in particular, can change during amplification. We demonstrate how the copropagating linear radiation acts as the energy source for the generation of new solitons. We believe that our results can be helpful for the future design of nonlinear transmission systems.

[1] A. Hasegawa, T. Nyu, J. Lightwave Technol. 11, 395-399 (1993).
[2] S. Turitsyn et al., Optica 4, 307-322 (2017).

[3] A. Hasegawa, Y. Kodama, Opt. Lett. 15, 1443-1445 (1990).

Q 29.6 Tue 15:15 K 0.016

Coherent control and wave mixing in a thin ensemble of silicon vacancy centers in diamond — •Johannes Görlitz[1], Christian Weinzetl[2], Jonas Nils Becker[1,2], Eilon Poem[3], Joshua Nunn[4], and Christoph Becher[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Clarendon Laboratory, University of Oxford, United Kingdom — [3]Weizmann Institute of Science, Rehovot 76100, Israel — [4]University of Bath, Claverton Down, Bath BA2 7AY, United Kingdom

In recent research the silicon vacancy center (SiV) in diamond received significant attention due to its favorable spectral properties such as a narrow zero phonon line (ZPL) and weak phonon side bands. At cryogenic temperatures the SiV reveals its four-line fine structure, related to a level scheme featuring orbital doublets of ground and excited state. These states constitute two optically accessible Lambda-schemes. We recently demonstrated ultrafast all optical coherent control between these orbital states showing the suitability of the SiV for quantum information processing. Due to its inversion symmetry and the resulting insensitivity to fluctuating environmental fields it is possible to grow dense SiV-ensembles with small inhomogeneous broadening, thus allowing for light matter interactions in the single photon regime. We here present Stimulated Raman adiabatic passage, Raman absorption as well as a stimulated Four Wave Mixing gain process in a dense ensemble of SiV centers. These processes reveal a strong light matter interaction and thereby pave the way for further applications like single photon switches or optically controlled quantum memories.

Q 29.7 Tue 15:30 K 0.016

Bulk-like emission of Silicon Vacancy centers in nanodiamonds after surface treatment — •Andrea Filipovski[1], Lachlan Rogers[2], Ou Wang[1], Valery Davydov[3], Viatcheslav Agafonov[4], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, Ulm, Germany — [2]Macquarie University, Sydney, Austrailia — [3]Russian Academy of Science, Moscow, Russia — [4]Université F. Rabelais, Tours, France

The negatively charged silicon vacancy center in diamond (SiV^-) is a promising candidate for quantum repeaters in solid state, due to its indistinguishable photon emission, high Debye Waller factor and spectral stability[1]. These extraordinary optical properties have only been reported in low-strain bulk diamond[2]. However, SiV^- in NDs which are favorable for integrated quantum systems, suffer from high strain resulting in large spectral instability.

Here we show bulk-like optical behavior of SiV^- in NDs with diameters below 150 nm after H-Plasma treatment. We recover single SiV^- with the typical 4-line fine structure, a high polarisation contrast and an inhomogeneous line width below 150 GHz with long term spectral stability. We developed a strain model consistent with our experimental data infering, for the first time, the zero-field splitting for SiV^- of $47.2^{+0.2}_{-0.3}$ GHz for the ground and 255^{+1}_{-2} GHz excited state. Suprisingly, almost 50% of the investigated SiV^- centers show strain values as low as best values reported for SiV^- in bulk diamond[3].

[1] L. J. Rogers et al, Nat. Comm.5, 2014, [2] A. Dietrich et al, NJP, Vol. 16, 2014, [3] L. J. Rogers et al, in preparation

Q 29.8 Tue 15:45 K 0.016

NV assisted spectroscopy and control of the local paramagnetic spin bath in 15N delta-doped diamond — •Florian Böhm[1], Nikola Sadzak[1], Claudia Widmann[2], Christoph Nebel[2], and Oliver Benson[1] — [1]AG Nanooptik, Humbodt-Universität zu Berlin, Germany — [2]Fraunhofer-Institut für Angewandte Festkörperphysik, Freiburg

The Nitrogen-vacancy (NV) center is amongst the most prominent defects in diamond, i.a. due to it's manipulable electron spin. However, the diamond matrix can also host other 'dark' paramagnetic impurities operating as a local spin bath interacting with the NV centers electron spin, leading to its decoherence [1].

In this work we use single shallow NV centers to investigate the nature and behaviour of the local bath environment in a 15N delta-doped [111] diamond using electron spin resonance (ESR) spectroscopy and probe its dynamics using double spin resonance [2]. By actively controlling the spin bath we can i.a. suppress the dephasing of the NV centers spin and measure the coupling strength between the NV sensor and different Nitrogen symmetry groups.

Our research aims at extending the coherence time of NV centers generated in diamond via implantation or delta-doping of 15N in order to enhance their magnetic field sensitivity.

[1] De Lange, G., et al. (2012). Sci. rep., 2, 382.
[2] Grotz, B., et al. (2011). New Jnl. of Phys., 13(5), 055004.

Q 30: Optomechanics II

Time: Tuesday 14:00–15:30 Location: K 0.023

Q 30.1 Tue 14:00 K 0.023

Laser Power Stabilization via Radiation Pressure — •Marina Trad Nery and Benno Willke — Albert Einstein Institute, Hannover, Germany

This work reports a new scheme for laser power stabilization in which power fluctuations of a laser beam are detected via radiation pressure produced on a micro oscillator. The ultimate goal of this experiment is to demonstrate an improved technique that can be implemented in the future generations of Interferometric Gravitational Wave Detectors. Since these interferometers are designed to detect differential length changes of around 10^{-18} m, they require high stability in the laser source: the Relative Power Noise needs to be on the order of 10^{-9} $Hz^{-1/2}$ at frequencies around 10 Hz, the most stringent requirement in experimental physics. At such levels, vacuum fluctuations limit the sensitivity in detecting power fluctuations in the traditional scheme and new techniques are necessary to overcome this limitation and reach the desired sensitivity. The advantages of the new technique will be presented together with the details of a proof-of-principle experiment that is currently being set up at the Albert Einstein Institute, Hannover.

Q 30.2 Tue 14:15 K 0.023

Thermal noise performance of metamirrors — •Johannes Dickmann[1], Carol Bibiana Rojas Hurtado[1], Ronny Nawrodt[2], and Stefanie Kroker[1,3] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Friedrich-Schiller-Universitaet Jena, Institut fuer Festkoerperphysik, Helmholtzweg 5, 07743 Jena, Germany — [3]Technische Universitaet Braunschweig, LENA Laboratory for Emerging Nanometrology, Pockelsstraße 14, 38106 Braunschweig, Germany

Many optical and optomechanical applications are limited by the thermal noise of their components (e.g. gravitational wave detectors and cavities for laser stabilization). In a wide spectral range, the Brownian thermal noise of the optical coatings dominates the noise level. Promising alternatives to conventional multilayer mirrors are nanostructured surfaces (so called metamirrors). We achieved a unified method for the calculation of Brownian thermal noise of arbitrary shaped linear optical elements based on the Fluctuation-Dissipation theorem approach. A semi-analytical investigation of Brownian thermal noise of binary sub-wavelength grating mirrors shows a decrease of the noise power spectral density by a factor of up to 10^4, compared to conventional mirrors under representative conditions.

Q 30.3 Tue 14:30 K 0.023

Investigation of silicon optical nanostructures for light modulation by optical forces — •Carol Bibiana Rojas Hurtado[1], Johannes Dickmann[1], Walter Dickmann[2], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt — [2]Technische Universität Braunschweig

A surface nanostructure is proposed as an optomechanical system, i.e. a system in which the optical modes interact with the mechanical modes via the radiation pressure. We investigate the optomechanical interaction for a resonance with high quality factor corresponding to the fundamental Transversal-Electric mode at a wavelength of about 1550 nm for near normal incidence. The structure consists of two layers of subwavelength silicon gratings on top of a silica substrate. The top grating sustains the optical modes while the bottom grating provides the mechanical susceptibility. The optical forces induced by the incoming light field lead to deformations in the gratings. We simulate that with static light fields, powers in the range of 5 mW lead to mechanical displacements in the picometer range. In our structure, this enables us to modulate the reflectivity of the surface between 35% and close to 100%. The displacement can be further enhanced by coupling it to the mechanical resonance of the structure with a modulation of the incoming light field at the eigenfrequency of the mechanical resonance. The proposed system allows the control of light with light and is promising for all-optical modulation for frequencies up to several hundreds of MHz.

Q 30.4 Tue 14:45 K 0.023

Fresnel-Reflection-Free Self-Aligning Nanospike Interface between a Step-Index Fibre and a Hollow-Core Photonic-Crystal-Fibre Gas Cell — •Riccardo Pennetta, Shangran Xie, Frances Lenahan, Manoj K. Mridha, David Novoa, and Philip St.J. Russell — Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058 Erlangen, Germany

The development of low-loss hollow-core photonic crystal fibres has opened new opportunities for investigating intense light-gas interactions over distances thousands of times longer than the Rayleigh length. In these experimental configurations, macroscopic gas cells or vacuum chambers are typically employed and laser light is launched into the system through windows using standard optical components. While effective, the resulting systems are bulky and sensitive to external perturbations, which is a crucial issue especially at high power levels, since even tiny misalignments can increase the overlap between the incident beam and the fibre microstructure. Here, we report a fully integrated interface delivering efficient, reflection-free, single-mode, and optomechanically self-aligned coupling between a step-index fibre and a gas-filled hollow-core photonic crystal fibre. Based on adiabatic evolution of the light field along a tapered silica nanospike, the device offers a universal solution for interfacing solid and hollow-core fibres. It can be sealed to allow operation either in ultra-high vacuum or at high pressure. As an example, stimulated Raman scattering and molecular modulation of light are demonstrated in a H2-filled hollow-core photonic crystal fiber using the device.

Q 30.5 Tue 15:00 K 0.023

Broadband optomechanically self-aligned coupling to liquid-filled hollow-core photonic crystal fibre using a fused silica nanospike — •Richard Zeltner, Riccardo Pennetta, Shangran Xie, and Philip St.J. Russell — Max Planck Institute for the Science of Light, Erlangen, Germany

Hollow-core photonic crystal fibre (HC-PCF) confines and guides light in a hollow core that can be filled with low index media, allowing efficient light-matter interactions over long path lengths. HC-PCF thus provide a promising platform for a variety of optofluidic experiments, for example in photochemistry and spectroscopy. Many applications require efficient and stable coupling of broadband light into the core modes, which can be challenging if free-space or butt-coupling are used. Here we introduce a new technique that permits broadband, optomechanically self-aligned light delivery into a liquid-filled HC-PCF. A fused silica nanospike, fabricated by thermally tapering and chemically etching a single-mode fibre to a final tip diameter of 350 nm, is inserted into the HC-PCF. When a strong laser beam is launched into the nanospike via the untapered fibre end, optomechanical interactions between the nanospike and the HC-PCF modes gives rise to strong optical forces that align the tip at core centre. With the tip trapped at core centre, a broadband (bandwidth of 500 nm) supercontinuum signal could be efficiently, and close to achromatically, launched into the HC-PCF. The optomechanical trapping forces render the coupling robust against perturbations and Fresnel back-reflections are decreased to insignificant levels compared to free-space or butt-coupling.

Q 30.6 Tue 15:15 K 0.023

Combined sympathetic and feedback cooling in an atom-optomechanical hybrid system — •Tobias Wagner[1], Philipp Christoph[1], Felix Klein[1], Hai Zhong[2], Alexander Schwarz[2], Roland Wiesendanger[2], Klaus Sengstock[1], and Christoph Becker[1] — [1]ZOQ-Center for Optical Quantum Technologies, Luruper Chaussee 149, 22761 Hamburg — [2]Institute of Applied Physics, University of Hamburg, Jungiusstraße 9-11, 20355 Hamburg

We present our latest efforts towards realization of a hybrid quantum system consisting of a quantum gas of bosonic atoms (e.g., a Bose-Einstein condensate) optically coupled to a cryogenically precooled mechanical oscillator operated at $T \approx 500\,\mathrm{mK}$. We routinely cool a high-stress $\mathrm{Si_3\,N_4}$ membrane to mean phonon occupancy of $\langle n \rangle \approx 16$ using combined quantum optical cooling schemes, i.e., sympathetic cooling with a laser cooled ensemble of atoms and active feedback cooling.

In this talk we will report in detail on the characterization and optimization of the combined cooling technique. We discuss possible improvements, which should allow us to cool the membrane further down into the ground state and open the door to investigate e.g. entanglement between membrane and BEC in this promising hybrid system. This work is supported by the DFG via grants of Wi1277/29-1, BE 4793/2-1 and SE 717/9-1.

Q 31: Quantum Effects (QED)

Time: Tuesday 14:00–15:45 Location: K 1.013

Q 31.1 Tue 14:00 K 1.013

Statistical and Geometrical Aspects of Atom-Surface Interaction in Dynamical Nonequilibrium — •Daniel Reiche[1,2], Francesco Intravaia[2], and Kurt Busch[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

The energy contained in fluctuations exactly equates that lost in dissipation, if both the system of interest and its environment are in thermodynamic equilibrium. This quantitative balance is a remarkable feature of open (quantum) systems and often serves as a conceptual basis for describing nonequilibrium situations. Indeed, it is commonly assumed that despite the system equilibrates not as a whole, separated subsystems equilibrate locally with their immediate surroundings. Relying on equilibrium results significantly reduces the technical complexity of computations, but neglects long-range correlations.

In the context of atom-surface interaction, we study the impact of nonequilibrium physics on quantum friction as well as Casimir-Polder interaction for planar geometries, e.g. a single half-space or a planar cavity. Considering a linear response of the particle to electromagnetic perturbations, we do not rely on any particular assumption on statistical measures such as Markovianity or Local Thermal Equilibrium. We place a special emphasize on the interplay between the chosen setup and the influence of nonequilibrium.

Q 31.2 Tue 14:15 K 1.013

Atom-surface interactions with nonlocal materials — •Francesco Intravaia[1], Daniel Reiche[1,2], and Kurt Busch[1,2] — [1]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany

The interaction between an atom and an extended body, such as a surface, is one of the oldest but also one of the most relevant problem of quantum physics. Indeed, due to the technological progress of recent years, atoms can be placed closer and closer to a material interface, which opens new horizons for quantum technologies and quantum-sensing. In this regime, however, some of the some of the simplifying assumptions used so far in the description of atom-surface interactions start to loose their validity. In particular the spatial dispersive properties of the material, neglected in most of the of the investigations reported in the literature, start to play a relevant role. Phenomena, such as the Landau damping, and new length scales, like the carrier's mean free path or the Thomas-Fermi screening length, induce fascinating behaviors which are completely absent in a local description of the electro-optical properties of the material.

We discuss here some relevant effects and recent results, which show the relevance of spatial dispersion in atom-surface interactions. The focus is on dispersion forces (non-charged objects) and on the interplay of nonlocality with quantum mechanics and nonequilibrium physics.

Q 31.3 Tue 14:30 K 1.013

Tailoring Quantum Friction with Superlattice Structures — •Marty Oelschläger[1,2], Francesco Intravaia[2], and Kurt Busch[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

Quantum friction is a drag force mediated by the electromagnetic vacuum fluctuations acting on an object in relative motion with respect to another. The characteristics of this interaction depend on the physical properties of the bodies as well as their details of the nano-structures. Here, we address two connected aspects of this non-equilibrium dispersion force: its strength and its behavior as a function of the kinematic and geometrical parameters that characterize the system. Specifically, we investigate the electromagnetic response of a superlattice structure, focusing on the low frequency plasmonic properties of the system and on the corresponding electromagnetic density of states. Since quantum friction strongly depends on these features, by tailoring the properties of the material we can control the drag force.

Q 31.4 Tue 14:45 K 1.013

Dispersion forces in multi-layered media — •Johannes Fiedler[1,2] and Stefan Y. Buhmann[1,3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [2]Centre for Materials Science and Nanotechnology, Department of Physics, University of Oslo, Oslo, Norway — [3]Freiburg Institute for Advanced Studies, Universität Freiburg, Freiburg, Germany

Dispersion forces are a result of the zero-point fluctuations of the electromagnetic field and are typically attractive for ground-state particles [1]. However, the presence of a medium environment allows for repulsion depending on the optical densities in the particular system. We present a method describing dispersion forces in planar multi-layered systems with continuous dielectric profile and illustrate the impact on Casimir and van der Waals forces with respect to the shape of the inhomogeneity [2]. For particles embedded in a medium we assume a cavity surrounding the particles to account for the impact of Pauli repulsion [3]. A combination of both methods can be applied to nano-sized ice particles below the ocean's surface. In this situation one finds a repulsive force with respect to the surface that prevents the particle from passing through the surface [4]. Depending on their size the particles levitate at specific distances to the surface due to the balance of buoyancy, Casimir-Polder and salt forces. Further, we illustrate the possibility of capturing methane in thin water layers surrounding ice.

[1] S.Y. Buhmann, Dispersion forces I (Springer Heidelberg, 2012). [2] J. Fiedler et al., in preparation. [3] J. Fiedler et al., J. Phys. Chem. A in press (2017), arXiv: 1710.04945. [4] P. Thiyam et al., in preparation.

Q 31.5 Tue 15:00 K 1.013

Casimir Force and Torque for Nonreciprocal Media and Applications to Photonic Topoligical Insulators — •Frieder Lindel[1,2], Sebastian Fuchs[1,2], and Stefan Yoshi Buhmann[1,3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]Department of Chemistry, University of British Columbia, Vancouver, British Columbia V6T 1Z1, Canada — [3]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg, Germany

The Casimir force was originally proposed as an attractive force between two perfectly conducting plates due to a reduced virtual photon pressure in the space between the plates. In macroscopic quantum electrodynamics (QED) the Casimir force was further generalised to bodies of arbitrary shape and material by realising that its existence stems from fluctuating charge carries within the materials.

We derive an even more general expression of the Casimir force within this framework of macroscopic QED for the case of bodies which break the Lorentz reciprocity condition and thus violate time reversal symmetry. We apply our result to a certain photonic topological insulator media, namely magnetised plasma with a static bias magnetic field to find that the Casimir force can be tuned by controlling the bias field. We further show that for certain configurations there exists a tunable Casimir torque which shows unique features due to unidirectional surface plasmons provided by the topological structure of the material.

Q 31.6 Tue 15:15 K 1.013

Plasma vs Drude modelling of the Casimir force: beyond the proximity force approximation — •Michael Hartmann[1], Gert-Ludwig Ingold[1], and Paulo A. Maia Neto[2] — [1]Universität Augsburg, Institut für Physik, 86135 Augsburg — [2]Instituto de Física, UFRJ, Rio de Janeiro, Brazil

We calculate the Casimir force and its gradient between a spherical and a planar gold surface [1]. Significant numerical improvements allow us to extend the range of accessible parameters into the experimental regime. We compare our numerically exact results with those obtained within the proximity force approximation (PFA) employed in the analysis of all Casimir force experiments reported in the literature so far. Special attention is paid to the difference between the Drude model and the dissipationless plasma model at zero frequency. It is found that the correction to PFA is too small to explain the discrepancy between the experimental data and the PFA result based on the Drude model. However, it turns out that for the plasma model, the corrections to PFA lie well outside the experimental bound obtained by probing the variation of the force gradient with the sphere radius [2]. The corresponding corrections based on the Drude model are significantly smaller but still in violation of the experimental bound for small distances between plane and sphere.

[1] M. Hartmann *et al.*, Phys. Rev. Lett. **119**, 043901 (2017)
[2] D. E. Krause *et al.*, Phys. Rev. Lett. **98**, 050403 (2007)

Q 31.7 Tue 15:30 K 1.013

A derivation of the resonance fluorescence spectrum with the resolvent-operator formalism — •Vincent Debierre and Zoltán Harman — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg

It is known that the spectrum of the light scattered by a two-level atom (the so-called Mollow spectrum) exhibits very different profiles in different intensity regimes. In particular, the incoherently scattered fraction of the incoming light is subdominant at low intensities and dominant at high intensities. Mollow has shown that the incoherent part takes over when the Rabi frequency of the light-atom interaction becomes larger than the natural linewidth of the excited atomic state. We derived [V. Debierre and Z. Harman, Phys. Rev. A **96**, 043835 (2017)] the Mollow spectrum in the resolvent operator formalism. The derivation is based on the construction of a master equation from the resolvent operator of the atom-field system. We show that, for electric dipole transitions, the natural linewidth of the excited atomic level remains essentially unmodified, to a very good level of approximation, even in the strong-field regime, where Rabi flopping becomes relevant inside the self-energy loop that yields the linewidth, ensuring that the obtained master equation and the spectrum derived matches that of Mollow. On the other hand, for non-electric dipole transitions (that can still be treated within the framework of the two-level approximation), our formalism predicts important modifications to the lifetime of the excited state in the strong-driving case.

Q 32: Precision Spectroscopy IV - highly charged ions (joint session A/Q)

Time: Tuesday 14:00–15:45 Location: K 1.016

Invited Talk Q 32.1 Tue 14:00 K 1.016

High precision hyperfine measurements in bismuth challenge bound-state strong field QED — •Rodolfo Sánchez — GSI, Darmstadt, Germany

High-resolution laser spectroscopy on the ground-state hyperfine splitting of hydrogen-like and lithium-like bismuth ions ($Bi^{82+,80+}$) has been carried out at the "Experimentier Speicherring" (ESR) at the GSI Helmholtz-Center for Heavy Ion Research in Darmstadt. The accuracy of the hyperfine splitting determination was improved by more than an order of magnitude compared to previous measurements and sufficient to test bound-state strong-field QED in the so-called specific difference between the two hyperfine splitting energies for the first time. We found a surprising discrepancy from the atomic theory predictions by more than 7σ. I will report on these measurements, possible explanations for this "hyperfine puzzle" of strong-field QED and on further activities that have been started to resolve this issue.

Q 32.2 Tue 14:30 K 1.016

X-Ray Spectroscopy of the KLL-Dielectronic Recombination Resonances with a Heidelberg Compact EBIT — •Peter Micke[1,2], Steffen Kühn[1], Jannik Dierks[2], Thomas Pfeifer[1], Piet O. Schmidt[2,3], Sven Bernitt[1,4], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Leibniz Universität Hannover, Germany — [4]Friedrich-Schiller-Universität Jena, Germany

The study of highly charged ions is of great interest for atomic, plasma and astrophysics, as well as fusion research. Moreover, their electronic levels include strongly enhanced contributions of special relativity and quantum electrodynamics. We have carried out high-resolution x-ray spectroscopy of the KLL dielectronic recombination resonances of highly charged argon and iron in one of the novel 0.86 T Heidelberg Compact Electron Beam Ion Traps (HC-EBIT). In this resonant process a free electron out of the EBIT's mono-energetic electron beam is captured into the L-shell of a trapped ion, promoting a second, bound K-shell electron into the L-shell. The excited intermediate state releases a K_α photon during decay, recorded by a high-purity Ge detector. We achieved an excellent electron-energy resolving power of more than 860 together with high relative accuracy for the resonance positions on the order of 50 to 100 meV by using a PTB calibrated high-precision voltage divider. By comparing our results with theoretical values, accurate absolute resonance energies can be deduced and atomic structure theory benchmarked.

Q 32.3 Tue 14:45 K 1.016

Identifications of optical transitions in highly charged ions for metrology and searches of variation of the fine-structure constant — •Hendrik Bekker[1], Julian Berengut[2], Anastasia Borschevsky[3], Nicky Potters[1], Julian Rauch[1], Alexander Windberger[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Insitüt für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]School of Physics, The University of New South Wales, Sydney NSW 2052 — [3]Van Swinderen Institute, Universiteit Groningen, Nijenborgh 4, 9747 AG Groningen

Compared to the neutral and singly charged ions that are used in current optical clocks, level-shifts due to external perturbations are greatly suppressed in highly charged ions (HCI). Furthermore, increased relativistic effects in HCI lead to a strong sensitivity to variation of the fine-structure constant α. Many HCI are predicted to have optical transitions suitable for laser spectroscopy due to level crossings. However, for these HCI, theory is not capable of predicting the energy level structures to the required precision. To address this issue, we investigated several of the proposed HCI, which we produced, trapped, and collisionally excited in the Heidelberg electron beam ion trap (HD-EBIT). The wavelengths of subsequent fluorescence light were determined at the ppm-level using a grating spectrometer. We present our latest results for $Ir^{16+,17+,18+}$ and $Pr^{9+,10+}$ which are used to benchmark state-of-the-art atomic theory calculations and to provide a deeper insight into the suitability of the proposed HCI for metrology purposes. This is a necessary step towards future laser spectroscopy.

Q 32.4 Tue 15:00 K 1.016

Electron-gun development for electron-ion crossed-beams experiments — •B. Michel Döhring[1], Alexander Borovik Jr.[1], Benjamin Ebinger[1], Kurt Huber[1], Tobias Molkentin[1], Alfred Müller[2], and Stefan Schippers[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen — [2]Institut für Atom- und Molekülphysik, Justus-Liebig-Universität Gießen

Reliable atomic data for electron impact ionisation of atoms are of crucial importance for the modelling of ionised-matter environments and other plasma related applications. To achieve a greater range of accessible electron energies and densities a new electron gun [1,2,3] that delivers a ribbon-shaped beam has been integrated into the experimental crossed-beams setup in Giessen. This gun is designed for electron energies from 10 to 3500 eV with high electron currents at all energies. Ten different electrodes provide a high degree of flexibility for choosing a number of operation modes. Here, we present the latest developments and the commissioning status of the high-power electron gun. In particular, we focus on the challenges associated with fast energy scan measurements.

[1] W. Shi et al., NIMB 205 (2003) 201-206.
[2] A. Borovik Jr. et al., J. Phys.: Conf. Ser. 488 (2014) 142007.
[3] B. Ebinger et al., NIMB 408 (2017) 317-322.

Q 32.5 Tue 15:15 K 1.016

Two-loop corrections to the bound-electron g-factor — •Bastian Sikora[1], Natalia S. Oreshkina[1], Halil Cakir[1], Vladimir A. Yerokhin[2], Christoph H. Keitel[1], and Zoltán Harman[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia

The g-factor of electrons bound in H-like ions can be measured and calculated with high accuracy. Comparisons between the theoretical and experimental values of the g-factor allow precision tests of QED and the determination of fundamental constants such as the electron mass or the fine-structure constant α [1].

In order to achieve high accuracy in theoretical predictions in heavy ions, the interaction with the nuclear potential needs to be taken into account to all orders in $Z\alpha$. Currently, the largest theoretical uncertainty arises from the two-loop self-energy corrections. We present all-order evaluations of the loop-after-loop self-energy contributions, and partial results for other diagrams, in which we treat the Coulomb interaction in intermediate states to zero and first order. – [1] V. A. Yerokhin, E. Berseneva, Z. Harman *et al.*, Phys. Rev. Lett. **116** 100801 (2016).

Q 32.6 Tue 15:30 K 1.016

Precision theory of the g factor of highly charged ions — •Zoltán Harman[1], Bastian Sikora[1], Halil Cakir[1], Vladimir A. Yerokhin[1,2], Natalia S. Oreshkina[1], and Christoph H. Keitel[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia

Quantum electrodynamic (QED) contributions to the electron g factor in strong binding fields have been tested to high precision in Penning trap measurements: an experiment with $^{28}Si^{13+}$ allowed to benchmark certain higher-order QED corrections for the first time [1]. Recently, the uncertainty of the electron mass has been largely decreased via measurements on the $^{12}C^{5+}$ ion [2], and by using the theoretical value of the g factor. In order to reduce theoretical uncertainties, we calculate further higher-order corrections.

An independent and improved determination of the fine-structure constant α may also be possible in near future employing a weighted difference of the g factors of the H- and Li-like ions of the same element. This weighted difference in chosen to maximize the cancellation of detrimental nuclear effects between the two charge states. It is shown that this method can be used to extract a value for α from bound-electron g-factor experiments with an accuracy competitive with or better than the present literature value [3]. – [1] S. Sturm *et al.*, Phys. Rev. Lett. **107** 023002 (2011); [2] S. Sturm *et al.*, Nature **506** 467 (2014); [3] V. A. Yerokhin *et al.*, Phys. Rev. Lett. **116** 100801 (2016).

Q 33: Quantum Information (Concepts and Methods) III

Time: Tuesday 14:00–16:00 Location: K 1.019

Group Report Q 33.1 Tue 14:00 K 1.019

Quantum imaging with incoherent X-rays — •Joachim von Zanthier — for the Quantum Imaging Collaboration: Department Physik, Universität Erlangen-Nürnberg, 91058 Erlangen; Department Physik, Universität Hamburg, 22761 Hamburg; Center for Free-Electron Laser Science, 22761 Hamburg; The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg; Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg

For more than 100 years, coherent diffraction of X-rays has been used to determine the structure of crystals and molecules. For this approach incoherence due to wavefront distortions or incoherent fluorescence emission - often the predominant scattering mechanism - is usually considered detrimental. Here we show that methods from quantum imaging, i.e., exploiting higher order intensity correlations, can be used to reconstruct and image the full 1D, 2D and even 3D arrangement of incoherently scattering objects [1-4]. Incoherent diffraction imaging allows for a significantly higher resolution compared to conventional coherent diffractive imaging techniques. We discuss a number of properties that are conceptually superior and point out that current free-electron lasers are ideally suited for the implementation of the approach [3]. We also present a first experimental demonstration in the soft X-ray domain, where we use higher-order intensity correlations to achieve higher fidelities and potentially a sub-Abbe resolution [4]. [1] S. Oppel et al., PRL 109, 233603 (2012). [2] A. Classen et al., PRL 117, 253601 (2016). [3] A. Classen et al., PRL 119, 053401 (2017). [4] R. Schneider et al., Nature Phys., published online October 30, 2017.

Q 33.2 Tue 14:30 K 1.019

Universality of weak values and its application to an efficient alignment method for interferometers — Jan Dziewior[1,2], Lukas Knips[1,2], Demitry Farfurnik[3], •Katharina Senkalla[1,2], Nimrod Benshalom[3], Jonathan Efroni[3], Jasmin Meinecke[1,2], Shimshon Bar-Ad[3], Harald Weinfurter[1,2], and Lev Vaidman[3] — [1]Max-Planck-Institute for Quantum Optics, Garching 85748 — [2]Department for Physics, Ludwig-Maximilians-University, Munich 80797 — [3]Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Tel-Aviv 69978

Weak values characterize the weak interactions of pre- and postselected quantum systems, in particular they provide a simple and universal description for different measurement pointers and observables. We demonstrate this universality by considering a photon in an interferometer with weak local interactions in one of its arms coupling to different degrees of freedom (DOF), like position $\hat{x}$, momentum $\hat{p}$, and polarization of the photon. We show theoretically and experimentally that different interactions in the same arm will all modify the pointer DOF in an universal way.

By considering misalignments of an interferometer as such a coupling to $\hat{x}$ and $\hat{p}$ we can provide an easy and efficient alignment method. We use the fact, that the centroid of the interference pattern is modified according to the weak value, which mainly depends on the phase, the relative intensity and the overlap of the two arms. Analyzing a single 2π phase scan taken by a single position sensing detector yields all necessary alignment parameters.

Q 33.3 Tue 14:45 K 1.019

Amplified measurement of a mode function's rotation — •Sabrina Hartmann, Joachim Fischbach, and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm

We present a complete quantum optical description of a Mach-Zehnder interferometer, including a Dove prism, which is rotated by a small angle compared to the plane of incidence [1]. The Dove prism changes polarization and rotates the mode function in one arm of the interferometer. Subsequently, by post-selecting photons at the output via polarization we identify an amplification of the mode function's rotation. This has been explained by the weak value formalism. We show, however, that this explanation is limited to a certain set of parameters. Furthermore, we evaluate the interferometric setup for several non-classical states and hence, determine conditions to obtain the above mentioned effect. The amplification of the mode function's rotation can also be observed in the second order correlation function.

[1] O.S. Magaña-Loaiza et al., *Physica Scripta*, **92**, 023001 (2016).

Q 33.4 Tue 15:00 K 1.019

Binary Homodyne Detection of Quadrature Squeezing over Satellite Links — •Christian R. Müller[1,2], Kaushik P. Seshadreesan[3,1,2], Gerd Leuchs[1,2,4], and Christoph Marquardt[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Erlangen, Deutschland — [2]Department Physik, Friedrich-Alexander-Universität Erlangen Nürnberg (FAU), Erlangen, Deutschland — [3]College of Optical Sciences, University of ArizonaTucson (AZ) USA — [4]Department of Physics and Max Planck Centre for Extreme and Quantum Photonics, University of Ottawa, Ottawa (ON), Canada

Optical satellite links are a promising candidate to overcome the distance limits of fiber-based quantum key distribution protocols [1]. Moreover, the vast distances and the varying gravitational potential renders optical satellite links an exciting testbed for probing the laws of physics at the interface between quantum mechanics and general relativity.

Quadrature squeezing is a nonlinear effect based on quantum correlations between photons in the optical signal. We demonstrate the feasibility of squeezing detection in a realistic scenario of an optical satellite link. Furthermore, we show that efficient squeezing detection is even feasible in the extreme case of a homodyne detector with merely one bit of resolution - a situation commonly found in long-haul optical communications. Our results pave the way for a timely and cost-efficient realization of fundamental tests of physics.

[1] K. Günthner et al., Optica (4)6 pp.611-616 (2017).

Q 33.5 Tue 15:15 K 1.019

Ergotropy and daemonic gain for multipartite systems — •Fabian Bernards[1], Otfried Gühne[1], Matthias Kleinmann[1], and Mauro Paternostro[2] — [1]Universität Siegen, Siegen, Germany — [2]Queen's University Belfast, United Kingdom

The emerging field of quantum thermodynamics tries to establish connections between thermodynamics and quantum mechanics. This connection brings up questions like 'How is the maximal extractable work from a quantum system related to its inherent classical and nonclassical correlations?' or 'Can entanglement help us to develop better work extraction protocols?'. The maximal amount of extractable work from a system when maximizing over all possible unitary time evolutions is called ergotropy. If the system is correlated to an ancilla, the maximal amount of extractable work can on average be increased by performing measurements on the ancilla before extracting the work from the system. This increased amount of extractable work is then called daemonic ergotropy and the average gain from performing optimal measurements on the ancilla is the daemonic gain. In [G. Francica et al., NPJ Quantum Information 3,12 (2017)] a connection was established between the daemonic gain and measures of correlations in the system such as concurrence. Additionally, numerical results were presented for the two-qubit case. In our contribution, we are going to present applications of the concepts above on higher-dimensional and multi-partite systems.

Q 33.6 Tue 15:30 K 1.019

Exponentially many monogamy and correlation constraints for multipartite states — •Christopher Eltschka[1], Felix Huber[2], Otfried Gühne[2], and Jens Siewert[3,4] — [1]Universität Regensburg, Regensburg, Germany — [2]Universität Siegen, Siegen, Germany — [3]Universidad del País Vasco UPV/EHU, Bilbao, Spain — [4]IKERBASQUE Basque Foundation for Science, Bilbao, Spain

By generalizing the universal state inversion map, we obtain local unitary invariants of degree 2 for arbitrary finite-dimensional multipartite quantum states, for which we systematically derive a set of independent equalities constraining the correlations in the system. The number of those equalities is exponential in the number of parties of the multipartite state.

The derived constraints represent linear inequalities for the linear entropies of the subsystems. For pure quantum states they turn into monogamy relations that constrain the distribution of entanglement among the subsystems of the global state.

Surprisingly, our method of derivation, which is based on the theory of entanglement — the universal state inverter was originally introduced in order to generalize the two-qubit concurrence to higher-dimensional bipartite systems — turns out to be directly linked to the generalized shadow inequalities proved by Rains [1].

[1] E. M. Rains, IEEE Trans. Inf. Theory **46**, 54 (2000)

Q 33.7 Tue 15:45 K 1.019

Even and odd components of correlations in multi-qubit systems — •Nikolai Wyderka, Felix Huber, and Otfried Gühne — Naturwissenschaftlich Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany

In multi-particle quantum systems correlations can arise between different sets of particles. A possible strategy is to divide the global correlations into two components, depending on the question whether they affect an odd or an even number of particles. For pure multi-qubit states we prove that these two components are inextricably interwoven and often one type of correlations completely determines the other. As an application, we prove that all pure qubit states with an odd number of qubits are uniquely determined among all mixed states by the odd component of the correlations. In addition, our approach leads to invariants under the time evolution with Hamiltonians containing only odd correlations and can simplify entanglement detection.

Q 34: Quantum Information (Quantum Communication)

Time: Tuesday 14:00–15:45 Location: K 1.020

Q 34.1 Tue 14:00 K 1.020

Coherent state coding approaches the capacity of non-Gaussian bosonic channels — •Stefan Huber and Robert König — Institute for Advanced Study & Zentrum Mathematik, Technische Universität München, 85748 Garching, Deutschland

The additivity problem asks if the use of entanglement can boost the information-carrying capacity of a given channel beyond what is achievable by coding with simple product states only. This has recently been shown not to be the case for phase-insensitive one-mode Gaussian channels, but remains unresolved in general. Here we consider two general classes of bosonic noise channels, which include phase-insensitive Gaussian channels as special cases: these are beamsplitters with general, potentially non-Gaussian environment states and classical noise channels with general probabilistic noise. We show that additivity violations, if existent, are rather minor for all these channels: the maximal gain in classical capacity is bounded by a constant independent of the input energy. Our proof shows that coding by simple classical modulation of coherent states is close to optimal.

Q 34.2 Tue 14:15 K 1.020

Optimal storage of a single photon in a single atom — •Luigi Giannelli[1], Tom Schmit[1], Stephan Ritter[2], Gerhard Rempe[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

We theoretically analyze the dynamics of a single photon propagating in free space and incident on the mirror of an optical cavity, in which an atom is trapped. Our purpose is to control the dynamics in order to store the photon in an atomic excitation. The cavity is modeled by a single mode and the relevant electronic states of the atom form a three-level Λ-system: one transition is coupled to the quantized field of the cavity via Jaynes-Cummings interaction, while the other transition is driven by a classical control field $\Omega(t)$. We optimize the temporal behavior of $\Omega(t)$ for the purpose of perfect photon storage. We consider several dissipative processes and compare the efficiency of adiabatic protocols, such as in [1-3]. We then develop a protocol in order to optimize the adiabatic transfer in presence of dissipative processes and determine its maximal fidelity. We then investigate the quantum speed limit of photon storage by means of optimal control theory (GRAPE algorithm).

[1] M. Fleischhauer, et al., Opt. Commun. 179, 395 (2000).
[2] A. V. Gorshkov, et al., Phys. Rev. A 76, 033804 (2007).
[3] J. Dilley, et al., Phys. Rev. A 85, 023834 (2012).

Q 34.3 Tue 14:30 K 1.020

Quantum state teleportation from a single ion to a single photon by heralded absorption — •Jan Arenskötter, Stephan Kucera, Matthias Kreis, Pascal Eich, Philipp Müller, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Quantum networks with trapped ions require interfaces between the nodes and channels and a resource of entanglement for long distance communication. Photon-pair sources based on spontaneous parametric down-conversion (SPDC) and tailored to match an atomic transition are such a resource [1]. Quantum state teleportation [2] provides a protocol for atom-photon interfaces, alternative to direct quantum state transfer [3].

We show the teleportation of a qubit encoded in the $D_{5/2}$ Zeeman sub-levels of the $^{40}Ca^+$ ion onto the polarization qubit of a single 854 nm photon. For this we use a cavity-enhanced SPDC source in Sagnac configuration, tunable and bandwidth-optimized for resonant interaction with the $^{40}Ca^+$ ion. The Bell state measurement of the teleportation protocol is implemented through heralded absorption of one photon of the pair [4]. The mean process fidelity of the teleportation after background correction is 86.3(23)%, and the mean overlap fidelity of the input states with the measured output states is 89.6(55)%.

[1] Haase et al., Opt. Let. **34**, 55 (2009).
[2] Bennett et al., Phys. Rev. Lett. **70**, 1895 (1993)
[3] Kurz et al., Phys. Rev. A **93**, 062348 (2016).
[4] Kurz et al., Nat. Commun. **5**, 5527 (2014).

Q 34.4 Tue 14:45 K 1.020

Propagation of high-dimensional twisted photons through atmospheric turbulence — •Timon Eichhorn, Giacomo Sorelli, Vyacheslav N. Shatokhin, and Andreas Buchleitner — Albert-Ludwigs-Universität, Freiburg i. Br.

Twisted photons are single excitations of electro-magnetic field modes characterized by helical phase fronts, and thus carry orbital angular momentum (OAM). The infinite dimension of the underlying Hilbert space makes these light modes potentially suitable for free space quantum communication. The main hurdle towards the latter application is the instability of twisted photons against turbulence-induced scattering into states lying outside the encoding subspace, leading, as a result, to the loss of information. We seek to identify high-dimensional OAM states which are most robust under such conditions, and present analytical as well as numerical results for the robustness of single photon superpositions of up to thirty OAM states.

Q 34.5 Tue 15:00 K 1.020

Protecting entanglement of twisted photons by adaptive optics — •Giacomo Sorelli[1], Nina Leonhard[2], Vyacheslav N. Shatokhin[1], Claudia Reinlein[2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Unversität Freiburg i. Br. — [2]Fraunhofer Institute for Applied Optics and Precision Egineering, Jena

Spatial excitations of the electromagnetic field carrying orbital angular momentum (OAM), often called twisted photons, can be used to encode high dimensional quantum (entangled) states. These states are not only of fundamental interest, but also practically useful, since they can enhance channel capacity and security in quantum communication. However, transmission across a turbulent atmosphere introduces random phase-fluctuations of the photon's wavefront that destroy the information therein encoded. In this talk we consider the propagation of OAM entangled qutrit and ququart states. We show how phase front correction by methods of adaptive optics can significantly reduce crosstalk to OAM modes outside the encoding subspace, and thereby improve stability of high dimensional entanglement in atmospheric turbulence.

Q 34.6 Tue 15:15 K 1.020

Can the EPR paradox be resolved without recourse to non-locality? — •Keerthan Subramanian[1,3] and Nirmal Viswanathan[2] — [1]Centre for Interdisciplinary Sciences, Tata Institute of Fundamental Research, Hyderabad 500107, India — [2]School of Physics, University of Hyderabad, Hyderabad 500046, India — [3]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, 69120 Heidelberg, Germany

Quantum mechanics is correct, but is it complete? This was the question raised by Einstein, Podolsky and Rosen(EPR) in 1935 through a gedanken experiment. Thanks to the work of Bohm and Bell states suggested by EPR were found to have mutually exclusive quantitative predictions from classical and quantum theories.

Most experiments that have been used to resolve the paradox have used non-locally correlated(aka entangled states) to demonstrate strong correlations in line with quantum mechanical predictions. Such experiments typically make use of the spin angular momentum(SAM) of photons. However, photons can also possess an orbital angular momentum(OAM) which is related to phase helicities. We demonstrate an interferometric scheme to perform OAM projections which when combined with SAM projections can measure correlations between the two. Subsequently by creating locally correlated SAM/OAM photon states that are non-separable and mathematically isomorphic with non-locally correlated states, we demonstrate strong correlations violating Bell's inequality thereby resolving the EPR paradox without recourse to non-locality.

Q 34.7 Tue 15:30 K 1.020

Distillation of Squeezing using an engineered downconversion source — •Thomas Dirmeier[1,2], Johannes Tiedau[3], Imran Khan[1,2], Vahid Ansari[3], Christian R. Müller[1,2], Christine Silberhorn[3], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institut für die Physik des Lichts, Staudtstr. 2, 91058 Erlangen — [2]Institut für Optik, Information und Photonik, FAU Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen — [3]Integrierte Quantenoptik, Angewandte Physik, Universität Paderborn, Warburgerstr. 100, 33098 Paderborn

Squeezed states are of interest in the quantum information processing or metrology context due to their distinguished non-classical feature - the noise reduction below shot noise in one of their phase quadratures. However, they are highly susceptible to losses during transmission.

This degradation can partially be countered by using suitable measurement protocols such as squeezing distillation. Our squeezing distillation protocol is based on subtracting photons from the squeezed modes and triggering a homodyne measurement on successful subtraction events. In our experiment, we optimize the operation parameters by employing an engineered PPKTP waveguide source to generate our squeezed states. With this, our source fulfills the demands of both, photon counting and homodyne measurements: a high brightness and a well-behaved spatial and spectral mode structure.

Q 35: Quantum Gases (Fermions) II

Time: Tuesday 14:00–16:15 Location: K 1.022

Q 35.1 Tue 14:00 K 1.022

Artificial gauge potentials in periodically driven optical lattices: numerical simulations of atomic transport — •Ana Hudomal[1], Ivana Vasić[1], Hrvoje Buljan[2], Walter Hofstetter[3], and Antun Balaž[1] — [1]Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Department of Physics, University of Zagreb, Croatia — [3]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, Frankfurt am Main, Germany

Artificial gauge potentials have been recently realized in cold-atom experiments with periodically driven optical lattices [1,2]. In such systems, atoms subjected to a constant external force gain an anomalous velocity in the direction transverse to the direction of the applied force. Taking into consideration realistic experimental conditions, we perform numerical simulations in order to investigate the dynamics of atomic clouds and relate it to the Chern number of the effective model. We use the full time-dependent Hamiltonian and take into account the effects of weak repulsive interactions between atoms. The results are compared to the semiclassical approximation.

[1] G. Jotzu et al., Nature **515**, 237 (2014).
[2] M. Aidelsburger et al., Nature Phys. **11**, 162 (2015).

Q 35.2 Tue 14:15 K 1.022

Experimental characterization and control of Floquet states in a periodically driven two-body quantum system — •Kilian Sandholzer, Rémi Desbuquois, Michael Messer, Frederik Görg, Joaquín Minguzzi, Gregor Jotzu, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, Zürich, Switzerland

Floquet engineering is a powerful tool to modify properties of a static system such as opening topological gaps or controlling magnetic order. The versatility of cold atom experiments offers the possibility to implement many of these schemes. Nonetheless, preparing a certain Floquet state that has the desired properties in this out-of-equilibrium situation is a more difficult task, especially when the driving frequency is close to a characteristic energy scale of the system. In this work, we prepare fermionic atoms in a driven optical lattice such that the system can be described by two interacting particles on a double well potential with a periodically modulated tilt. In the case of near-resonant driving we achieve to enter adiabatically individual Floquet states by using a two-step ramping protocol. In addition, the fast coherent dynamics inherently connected to the drive are studied in detail. Finally, an analytical derivation of the effective time-independent Hamiltonian of the realized system is presented and then compared to numerical studies and experimental data.

Q 35.3 Tue 14:30 K 1.022

Dynamics of driven interacting many-body systems — •Michael Messer, Frederik Görg, Kilian Sandholzer, Joaquín Minguzzi, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Periodic driving can be used to coherently control the properties of a many-body state and to engineer new phases which are not accessible in static systems. The successful implementation of a periodically driven Fermi-Hubbard model on a 3D hexagonal lattice offers the possibility to explore the intriguing dynamics of Floquet many-body systems. A theoretical analysis of driven many-body Hamiltonians is inherently challenging, however, in combination with our experiments a deeper understanding seems feasible.

By controlling the detuning between shaking frequency and interactions, and setting a variable strength of the periodic drive, we achieve independent control over the single particle tunneling and the magnetic exchange energy. This control allows us to investigate the dynamics and build-up of nearest-neighbor spin-spin correlations. Furthermore, we explore possible mechanisms behind the formation of correlations in interacting Floquet systems. In addition, we can analyze the creation of double occupancies, as one mechanism to form excitations.

Q 35.4 Tue 14:45 K 1.022

Enhancement and sign change of magnetic correlations in a driven quantum many-body system — •Frederik Görg[1], Michael Messer[1], Kilian Sandholzer[1], Joaquín Minguzzi[1], Gregor Jotzu[1,2], Rémi Desbuquois[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany

Strong periodic driving can be used to control the properties of interacting quantum systems. In solid state experiments, ultrashort laser pulses are employed to tune the charge order as well as magnetic and superconducting properties of materials. At the same time, continuous driving has been used in cold atom experiments to engineer novel effective Floquet-Hamiltonians which feature for example a topological bandstructure. We realize a strongly interacting Fermi gas in a periodically driven hexagonal optical lattice and investigate its charge and magnetic properties. We first demonstrate that in the high-frequency regime, the effective description of the many-body system by a renormalized tunnelling amplitude remains valid by comparing our results to an equivalent static system. When driving at a frequency close to the interaction energy, we show that anti-ferromagnetic correlations can be enhanced or even switched to ferromagnetic ordering. Our observations can be explained by a microscopic model, in which the particle tunnelling and magnetic exchange energies can be controlled independently. Therefore, Floquet engineering constitutes an alternative route to experimentally investigate unconventional pairing.

Q 35.5 Tue 15:00 K 1.022

Manipulating and probing excitations of a Chern insulator by Floquet engineering an optical solenoid — •Botao Wang, Nur Ünal, and André Eckardt — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The realization of artificial gauge fields in optical lattice systems has paved a way to the experimental investigation of various topological quantum effects. Here we propose a realistic scheme for realizing tunable local (solenoid type) artificial magnetic fields by means of Floquet engineering. We show that such an optical solenoid field can be used to coherently manipulate and probe Chern insulator states of the Hofstadter Hamiltonian. In particular, we investigate the possibility to create local quasiparticle and quasihole excitations, to coherently populated edge modes, and to achieve quantized charge pumping. All these effects are manifested on the spatial density distributions, which can be measured directly in quantum-gas microscopes.

Q 35.6 Tue 15:15 K 1.022

Characterizing topology by dynamics: Chern number from linking number — •Matthias Tarnowski[1,2], Nur Ünal[3], Nick Fläschner[1,2], Benno Rem[1,2], André Eckardt[3], Klaus Sengstock[1,2,4], and Christof Weitenberg[1,2] — [1]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany — [3]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany — [4]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany

Topology plays an important role in modern solid state physics describing intriguing quantum states such as topological insulators. It is an intrinsically non-local property and therefore challenging to access, often studied only via the resulting edge states. Here, we report on a new approach by connecting the Chern number with the dynamical evolution of highly excited states of the system and demonstrate it experimentally with cold atoms in hexagonal optical lattices. We study the contour of dynamically created vortex pairs in momentum space following a sudden quench into the system of interest and infer the Chern number of the post-quench Hamiltonian from the topology of the contour, quantified by the linking number with the static vortices. Our work exploits a direct mapping between two topological indices and allows detecting topology by the naked eye.

Q 35.7 Tue 15:30 K 1.022

1D fermionic Floquet topological insulators with Hubbard interaction — •Haixin Qiu[1] and Johann Kroha[1,2] — [1]Physikalisches Institut and Bethe Center for Theoretical Physics, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Center for Correlated Matter, Zhejiang University, Hangzhou, Zhejiang 310058, China

The fermionic Rice-Mele model is a standard model for quantum ratchet transport in periodically driven, one-dimensional, bipartite chains. In the adiabatic limit, this model exhibits quantized transport (Thouless pump), while in the limit of fast drive quasistatic approximations with effective hopping parameters are possible. Here we study the Rice-Mele model with periodic drive of both, the hopping amplitudes and the onsite energy modulation,in the intermediate regime where the driving frequency is comparable to intrinsic energy scales. In this regime, topological Floquet-Bloch bands are possible because of an effectively two-dimensional Brillouin zone comprised of the periodic k-space and the periodic, continuous time space. We investigate the stability of the topological phase with respect to inelastic interactions. To that end, we include a Hubbard onsite repulsion U in the Floquet Hamiltonian of the Rice-Mele model. The Floquet space is truncated with up to ± 5 Floquet bands. We develop the Keldysh-Floquet Green's function method for stationary non-equilibrium, which is non-trivial already in the non-interacting case because of the bipartite lattice structure. The Hubbard interaction is treated by 2nd-order selfconsistent perturbation theory in U. We present results for the Floquet spectral densities and the transport current.

Q 35.8 Tue 15:45 K 1.022

Strong field QED effect of spontaneous pair creation from vacuum simulated in a 2D optical lattice — Leonhard Klar, •Nikodem Szpak, and Ralf Schützhold — Faculty of Physics, University of Duisburg-Essen, Germany

QED predicts the decay of quantum vacuum and spontaneous creation of electron–positron pairs for sufficiently strong electric fields which, however, could not be reached in any laboratory so far. A promissing alternative, opening this fascinating field to experiments, is offered by optical lattice based quantum simulators [1,2] in which ultra-cold atoms behave in an analogue way to electrons and positrons in QED. We propose a two-dimensional optical lattice setup filled with cold fermions in which excitations of the ground state behave as particles and antiparticles (holes) and satisfy the relativistic Dirac equation. We calculate the pair production rates for slowly varying time-dependent external fields and show that vacuum destabilization occurs only for supercritical fields as predicted by QED [3].

[1] N. Szpak and R. Schützhold, Phys. Rev. A 84, 050101(R) (2011).
[2] N. Szpak and R. Schützhold, New J. Phys. 14 (2012) 035001.
[3] N. Szpak, J. Phys. A: Math. Theor. 41 (2008) 164059 (7pp).

Q 35.9 Tue 16:00 K 1.022

Versatile detection scheme for topological Bloch-state defects — •Marlon Nuske[1], Matthias Tarnowski[2,3], Nick Fläschner[2,3], Benno Rem[2,3], Dominik Vogel[2], Klaus Sengstock[1,2,3], Ludwig Mathey[1,2,3], and Christof Weitenberg[2,3] — [1]Zentrum für optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

The dynamics in solid state systems is not only governed by the band structure but also by topological defects of the Eigenstates. A paradigmatic example are the Dirac points in graphene. For this system with a two-atomic basis the linear dispersion relation at the Dirac points is accompanied by a vortex of the azimuthal phase of the Eigenstates. In a time-of-flight (ToF) expansion the Eigenstates interfere and the resulting signal contains information about the azimuthal phase. We present a versatile detection scheme that uses off-resonant lattice modulation to extract the azimuthal phase from the ToF signal. This detection scheme is applicable to a variety of two-band systems and can be extended to general multi-band systems.

Q 36: Ultracold Molecules

Time: Tuesday 14:00–15:30 Location: K 2.013

Q 36.1 Tue 14:00 K 2.013

A Cryofuge enabling cold collision studies for sympathetic and evaporative cooling of polar molecules — •Thomas Gantner, Manuel Koller, Xing Wu ø, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, 85748 Garching, Deutschland

Understanding molecular collisions at low energies is a prerequisite for future sympathetic and evaporative cooling of naturally occurring molecules. However, experimental investigation of collisions in the cold ($T < 1K$) and ultracold ($T < 1mK$) temperature regime is still in its infancy. Open questions include ratios of elastic and inelastic collision rates and the possible existence of so-called sticky collisions. Our Cryofuge setup, the combination of centrifuge deceleration [1] and buffer gas cooling, produces slow molecular beams with densities of over $10^9/cm^3$ and thereby enables the observation of cold molecular collisions. The dipolar nature of these collisions leads to large observed cross sections ($> 10^{-12}cm^2$) with theoretically modeled elastic and inelastic collisional loss rates agreeing with the experimental findings [2]. As a next step, the molecules are loaded into an electrostatic trap [3] enabling much more detailed studies due to longer interaction times. Such measurements are expected to lay the basis for future cooling of polyatomic molecules to quantum degeneracy.

[1] S. Chervenkov et al., Phys. Rev. Lett. 112, 013001 (2014)
[2] X. Wu et al., Science 358, 645-648, (2017)
[3] B.G.U. Englert et al., Phys. Rev. Lett. 107, 263003 (2011)
ø Now at: Departments of Physics, Yale and Harvard University

Q 36.2 Tue 14:15 K 2.013

Reaction kinetics in ultracold molecule-molecule collisions — •Daniel Hoffmann, Thomas Paintner, Wolfgang Limmer, and Johannes Hecker Denschlag — Institut für Quantenmaterie, Universität Ulm, Deutschland

We study the dissociation of ultracold molecules of fermionic ^{6}Li atoms in cold molecular collisions. For this we prepare an almost pure gas of Feshbach dimers (BEC regime) in a single internal quantum state and trigger the dynamics by slightly increasing the temperature of the molecular ensemble. The dissociation dynamics are measured by counting the number of unpaired atoms as a function of time. Fitting a model to the data allows us to extract the reaction rate constant of the dissociation. Furthermore, we determine how the dissociation rate constant depends on the temperature and interaction strength and find a strong scaling behavior for both quantities.

Q 36.3 Tue 14:30 K 2.013

State-to-state chemistry at ultralow temperature — •Markus Deiss[1], Joschka Wolf[1], Artjom Krükow[1], Eberhard Tiemann[2], Brandon P. Ruzic[3], Yujun Wang[4], José P. D'Incao[5], Paul S. Julienne[3], and Johannes Hecker Denschlag[1] — [1]Institut für Quantenmaterie and Center for Integrated Quantum Science and Technology IQST, Universität Ulm, 89069 Ulm, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Joint Quantum Institute, University of Maryland, and the National Institute of Standards and Technology (NIST), College Park, MD 20742, USA — [4]American Physical Society, Ridge, NY 11961, USA — [5]JILA, NIST, and the Department of Physics, University of Colorado, Boulder, CO 80309, USA

A primary and long-standing goal of state-to-state chemistry is the determination of the quantum states of the final products given the quantum state of reactants. We have recently developed and demonstrated a method to probe diatomic molecular product states of reactive processes both qualitatively and quantitatively [1]. Using the given method we have investigated the recombination of three neutral rubidium atoms resulting in a dimer and a free atom. In this talk, we present our recent results on state-to-state chemistry for this fundamental reactive process.

[1] J. Wolf *et al.*, Science 358, 921 (2017)

Q 36.4 Tue 14:45 K 2.013

Feshbach spectroscopy and dual-species Bose-Einstein condensation of 23Na-39K mixtures — •Torben Schulze, Torsten Hartmann, Kai Voges, Philipp Gersema, Eberhard Tiemann, Alessandro Zenesini, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

Mixtures of quantum degenerate gases of chemically different atomic species provide a rich testbed for quantum simulation including the study of beyond mean-field quantum droplets and diatomic polar molecules for the formation of supersolid materials. In this talk, we present the first ever creation of quantum degenerate Bose-Bose mixtures of ^{23}Na and ^{39}K. We present calculations and measurements of scattering rate constants and the previously unknown interspecies Feshbach spectrum in a magnetic field window up to 700 Gauss. Based on the gained understanding, we show the suitability of our mixture for the studies of phase separation and quantum droplets.

Q 36.5 Tue 15:00 K 2.013

Coherent manipulations of rotational states of 23Na40K molecules in a 1D optical lattice — •Xinyu Luo[1], Frauke Seesselberg[1], Ming Li[3], Scott Eustice[1], Svetlana Kotochigova[3], Immanuel Bloch[1,2], and Christoph Gohle[1] — [1]Max-PlanckInstitut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany — [3]Department of Physics, Temple University, Philadelphia, PA 19122-6082, USA

Ultracold polar molecule gases, promising strong electric dipole-dipole interaction and a long lifetime in a 3D optical lattice, are good candidates for investigating many-body physics with long-range interactions. Rotational states of these molecules with opposite parity offer strong dipole-dipole interaction. They can thus be used to simulate long range interaction beyond nearest-neighbor interaction even in a deep lattice. To leverage the rotational degree of freedom in a spatially inhomogeneous optical lattice, however, one needs to deal with a light intensity dependent differential AC Stark shift between rotational states. Trap field polarization can be used to cancel it to first order. Here we show that the remaining high order differential AC Stark shift of 23Na40K molecule can be reduced significantly when the nuclear spin is decoupled from the molecular rotation by applying a DC electric field. Therefore the single particle dephasing of the rotating dipoles would be significantly reduced. Our work paves the way to observe interaction effect by Ramsey interferometery of molecules without dynamical decoupling.

Q 36.6 Tue 15:15 K 2.013

Ferroelectric nano-traps for polar molecules — Omjyoti Dutta[1] and •Geza Giedke[1,2] — [1]Donostia International Physics Center (DIPC), Donostia-San Sebastian, Spain — [2]Ikerbasque Foundation, Bilbao, Spain

We propose and analyze an electrostatic-optical nanoscale trap for cold diatomic polar molecules. The main ingredient of our proposal is an square-array of ferroelectric nanorods with alternating polarization. We show that, in contrast to electrostatic traps using the linear Stark effect, a quadratic Stark potential supports long-lived trapped states. The molecules are kept at a fixed height from the nanorods by a standing-wave optical dipole trap. For the molecules and materials considered, we find nanotraps with trap frequency up to 1MHz, ground-state width on the order of 20nm. Analyzing the loss mechanisms due to non-adiabaticity, surface-induced radiative transitions, and laser-induced transitions, we show the existence of trapped states with life-time on the order of 1s, competitive with current traps created via optical mechanisms. As an application we extend our discussion to an 1D array of nanotraps to simulate a long-range spin Hamiltonian in our structure.

Q 37: Quantum Gases (Bosons) IV

Time: Tuesday 14:00–16:00 Location: K 2.020

Q 37.1 Tue 14:00 K 2.020

Fluctuation-dissipation relations and finite compressibility of a grand canonical Bose-Einstein condensate — •Fahri Emre Ozturk[1], Tobias Damm[1], David Dung[1], Christian Kurtscheid[1], Erik Busley[1], Frank Vewinger[1], Julian Schmitt[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany — [2]Present address: Cavendish Laboratory, University of Cambridge, J.J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom

We measure the density fluctuations and the isothermal compressibility of a two-dimensional photon Bose-Einstein condensate confined in a dye microcavity. The photon gas is coupled to a reservoir of molecular excitations, which serves both as a heat bath and a particle reservoir [1]. This leads to grand canonical statistical behavior with photon number fluctuations which can be as large as the average condensate photon number [2]. In thermal equilibrium, such fluctuations are related to the isothermal compressibility and the thermal energy $k_B T$. We report on the progress of an ongoing experiment investigating this relation, expressed by the fluctuation-dissipation theorem, for the condensed photon gas.

[1] Klaers et al., *Nature* **468**, 545 (2010)
[2] Schmitt et. al., *Phys. Rev. Lett.* **112**, 030401 (2014)

Q 37.2 Tue 14:15 K 2.020

Modeling Dye-Mediated Photon-Photon Interaction in Condensates of Light — •Milan Radonjić[1], Wassilij Kopylov[2], Antun Balaž[1], and Axel Pelster[3] — [1]Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Department of Physics, Technische Universität Berlin, Germany — [3]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Based entirely on the Lindblad master equation approach we obtain a microscopic description of photons in a dye-filled cavity, which features condensation of light [1,2]. To this end we generalize the nonequilibrium approach of Ref. [3] such that the dye-mediated contribution to the photon-photon interaction in the light condensate is accessible. We describe the dynamics of the system by analyzing the resulting equations of motion. In particular, we discuss the existence of two limiting cases for steady states: photon BEC and laser-like. In the former case, we determine the corresponding dimensionless interaction strength relying on realistic experimental data and find a good agreement with the previous theoretical estimate [4]. Furthermore, we investigate how the dimensionless interaction strength depends on the respective system parameters such as the effective temperature of the dye and the number of the dye molecules.

[1] J. Klaers et al., Nature **468**, 545 (2010)
[2] R. A. Nyman and M. H. Szymanska, Phys. Rev. A **89**, 033844 (2014)
[3] P. Kirton and J. Keeling, Phys. Rev. Lett. **111**, 100404 (2013)
[4] E. C. I. van der Wurff et al., Phys. Rev. Lett. **113**, 135301 (2014)

Q 37.3 Tue 14:30 K 2.020

Photon Condensates in Microstructured Trapping Potentials — •Christian Kurtscheid[1], David Dung[1], Erik Busley[1], Julian Schmitt[2], Tobias Damm[1], Frank Vewinger[1], Jan Klärs[3], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]present address: Department of Physics, University of Cambridge, JJ Thomson Avenue, Cambridge, United Kingdom — [3]present address: Faculty of Science and Technology, University of Twente, Horst- Meander 123, Enschede, The Netherlands

In earlier work, Bose-Einstein condensation of photons has been re- alized in a dye- lled optical microcavity at room temperature. The short mirror spacing of the curved mirror microcavity introduces a low- frequency cuto , and thermal contact to the dye solution is achieved by subsequent absorption and re-emission processes. In the present work, we present recent results on a thermo-optic technique to generate variable potentials for light within a supermirror optical microcavity. The long photon lifetime allows for the thermalization of photons and the demonstration of a microscopic photon condensate with a critical photon number of 68. We observe e ective photon interactions as well as the tunnel coupling between microsites. We also report on a delamination technique realising static potentials in the dye microcavity environment.

Q 37.4 Tue 14:45 K 2.020

QED treatment of the photon BEC in arbitrary geometries: Coupled dissipative dynamics of dye molecules — •Yaroslav Gorbachev[1], Robert Bennett[1], and Stefan Yoshi Buhmann[1,2] — [1]Institute of Physics, University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), University of Freiburg, Germany

Progress in photonics over the last few years has led to a new challenge in quantum optics: the photon BEC. This has been experimentally observed in a small microcavity filled with a dye medium [1]. Confinement of laser light within such an optical microcavity creates conditions for light to equilibrate as a gas of conserved particles. We use the language of macroscopic quantum electrodynamics [2] together with theory of open quantum systems [3] to describe this phenomenon. We are interested in realistic description of the cavity geometry, whose frequency dependent reflection and absorption are fully encoded in the classical Green's function for the electromagnetic Helmholtz equation. This extension of the standard Jaynes-Cummings model to absorbing cavities with realistic geometries opens the door to studying the effects of discrete mode coupling in a resonant geometry to the strong body-assisted electromagnetic field of the cavity.

[1] J.Klaers, J.Schmitt, F. Vewinger, and M. Weitz, Nature (London) 468, 545 (2010)

[2] S.Y.Buhmann, Dispersion Forces I, Springer, Berlin Heidelberg, 2012

[3] P. Kirton, J.Keeling, Phys.Rev. A 91, 033826 (2015)

Q 37.5 Tue 15:00 K 2.020

Mode selection in a system of photons in a dye-filled microcavity — •Martina Vlaho, Daniel Vorberg, Alexander Leymann, and André Eckardt — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We investigate the non-equilibrium steady state of a gas of photons in a dye-filled microcavity as it has been realized by the Weitz group. We consider the regime where the system is pumped away from the cavity center so that the pump spot predominantly overlaps spatially with excited transverse photon modes. We observe that when increasing the pump rate above a threshold, such an excited mode acquires a macroscopic occupation, i.e., becomes selected. Ramping up the pump rate further, we find that the ground mode can become selected for a given range of system parameters, resulting from an increased density of excited state molecules in the cavity center, once the excited mode gets selected. We also consider the case of a homogeneously pumped system where we observe a cascade of transitions between the selected modes. We find that a blocking mechanism between modes with a large spatial overlap effects which modes are selected before saturation takes place.

Q 37.6 Tue 15:15 K 2.020

Towards photon Bose-Einstein condensation in a quantum dot microcavity — •Thilo vom Hövel, Christian Kurtscheid, David Dung, Erik Busley, Tobias Damm, Hadiseh Alaeian, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Bose-Einstein condensation has been achieved with cold atoms, exciton-polaritons, and more recently with photons in a dye-filled optical microcavity. In the latter work, thermalization of the photon gas is achieved by subsequent absorption and re-emission cycles of photons in the dye molecules. A non-trivial energy ground state is created by the long-wavelength cutoff introduced by the short mirror separation of the used cavity.

In the present work, semi-conductor quantum dots are investigated as a potential alternative to organic dyes as thermalization mediator. For this, the applicability of the Kennard-Stepanov theory to quantum dot absorption and emission spectra has been investigated. We are currently working on the observation of thermalization and Bose-Einstein condensation of photons in a quantum dot-filled optical microcavity. The current status of the experiment will be presented.

Q 37.7 Tue 15:30 K 2.020

Collective Frequencies of Trapped Photon Bose-Einstein Condensate — •Enrico Stein and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

In a photon Bose-Einstein condensate the main contribution to the effective photon-photon interaction is due to a thermooptic effect [1]. In order to describe this effect at a mean-field level, we use an open-dissipative Schrödinger equation coupled to a diffusion equation for the temperature of the dye solution [2]. With this we calculate analytically the lowest-lying collective frequencies and damping rates via a linear stability analysis for a harmonically trapped photon BEC. Since it is not possible to investigate its dynamical properties within a variational approach by using an action, we work out an approximation which is based on determining the equations of motion for the lower moments for Gaussian shaped condensate wave function and temperature distribution. As a result of the photon-temperature coupling the collective frequencies and damping rates turn out to depend on the diffusive properties of the dye solution. In particular, we examine whether the Kohn theorem is valid, i.e. whether the dipole-mode frequency is the same as the trap frequency [3,4].

[1] J. Klaers et al., Appl. Phys. B **105**, 17 (2011)
[2] D. Dung et al., Nature Photonics **11**, 565 (2017)
[3] A. L. Fetter and D. Rokhsar, Phys. Rev. A **57**, 1191 (1998)
[4] H. Al-Jibbouri and A. Pelster, Phys. Rev. A **88**, 033621 (2013)

Q 37.8 Tue 15:45 K 2.020

Towards a Photon Bose-Einstein Condensate in the Vacuum-Ultraviolet Spectral Regime — •Christian Wahl, Marvin Hoffmann, Frank Vewinger, and Martin Weitz — IAP, Universität Bonn

We propose an experimental approach for photon Bose-Einstein condensation in the vacuum-ultraviolet spectral regime, based on the thermalisation of photons in a noble gas filled optical microcavity. Our current experiments realizing photon Bose-Einstein condensates operate in the visible spectral regime with organic dyes as a thermalisation medium [1]. To reach the vacuum-ultraviolet spectral regime, we plan to replace the dye medium by high pressure xenon or krypton gas with absorption re-emission cycles on the transition from the ground to the lowest electronically excited state of the noble gases for thermalisation. In order to achieve sufficient spectral overlap between the atomic absorption and the di-atomic excimer emission, noble gas pressures of up to 180 bar will be created inside the cavity. For the case of the heavier noble gases xenon and krypton, emission wavelengths in the 120-160 nm regime seem feasible. The current status of experimental work will be reported.

References
[1] J. Klaers et al. Nature 468, 545-548 (2010)

Q 38: Poster: Quantum Optics and Photonics I

Time: Tuesday 16:15–18:15 Location: Orangerie

Q 38.1 Tue 16:15 Orangerie

Mean-Field Dynamics of a Homogeneous Photon Bose-Einstein Condensate — Enrico Stein and •Axel Pelster — Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

We show, that a Bose-Einstein condensate of photons [1,2] can be described consistently on the mean-field level by using an open-dissipative Gross-Pitaevski approach as it is widely used in the community of exciton-polariton condensates [3,4]. In our context this means to set up a pair of coupled mean-field equations, one for the coherent condensate wave function and one for the diffusion of temperature in the dye solution. With this mean-field approach at hand we perform a linear stability analysis for a homogeneous photonic BEC. At first, we determine the steady state, from which we deduce a photon-photon interaction strength agreeing with the experimental value [2,4]. Afterwards, we analyze small deviations from the BEC steady state, yielding both the Bogoliubov spectrum and its damping. In particular, we show that the Goldstone theorem turns out to be valid even for such an open-dissipative photonic system. Finally, we note that our mean-field modelling yields for experimenal realistic parameters a stable BEC steady state as both pumping and dissipation are included.

[1] J. Klaers et al., Nature **468**, 545 (2010)
[2] J. Klaers et al., Appl. Phys. B **105**, 17 (2011)
[3] M. Wouters and I. Carusotto, Phys. Rev. Lett. **99**, 140402 (2007)
[4] D. Dung et al., Nature Photonics **11**, 565 (2017)

Q 38.2 Tue 16:15 Orangerie

The Space Atom Laser - An isotropic source for ultra-cold atoms in microgravity — •Matthias Meister, Albert Roura, Wolfgang P. Schleich, and The QUANTUS Team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm

Atom laser experiments based on magnetically trapped Bose-Einstein condensates (BECs) performed on ground allow to create an accelerated, directed beam of atoms due to gravity. In microgravity, on the other hand, the dominant force acting on the outcoupled atoms is the repulsive interaction between the particles resulting in a slowly expanding three-dimensional shell. Remarkably, this outcoupled shell possesses a fairly isotropic distribution in position and momentum even when the initial BEC was trapped in an elongated, anisotropic trap.

We present a realistic protocol that allows the generation of such an unusual arrangement of atoms in microgravity by applying radio frequency outcoupling methods to a magnetically trapped BEC. In order to pave the way for its experimental implementation in NASA's Cold Atom Laboratory on the ISS, we have thoroughly studied this process numerically including experimental imperfections like fluctuating particle numbers or instabilities of the magnetic trap.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1556.

Q 38.3 Tue 16:15 Orangerie

Calorimetry and Coherence of a Photon Bose-Einstein Condensate — •Erik Busley[1], Julian Schmitt[2], Tobias Damm[1], David Dung[1], Fahri Öztürk[1], Christian Kurtscheid[1], Jan Klärs[3], Frank Vewinger[1], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, CB3 0HE Cambridge, United Kingdom — [3]Faculty of Science and Technology, University of Twente, De Horst 2, 7522LW Enschede, Netherlands

We have in earlier work experimentally realized Bose-Einstein condensation of photons. The condensate is generated in a dye-filled optical microcavity which provides a photon dispersion equivalent to harmonically trapped massive bosons. Thermalization of the photon gas is achieved by subsequent absorption and emission cycles in the dye molecules which fulfill the Kennard-Stepanov relation.

Here we report on recent results regarding the caloric properties of the photon condensate. The specific heat shows a cusp singularity at the phase transition similar to liquid helium. Also, the internal energy per particle shows the expected behavior for a phase transition. More recently, we have investigated the first-order coherence of the photon gas below and above condensation threshold. Tunable Michelson and Mach-Zehnder interferometers are used to split up and recombine the cavity emission to obtain temporal and spatial coherence. The interferometrically measured coherence times range from picoseconds below criticality to microseconds above the condensation threshold.

Q 38.4 Tue 16:15 Orangerie

Reservoir-induced collapse and revival of photon-BEC oscillations — Bastian Havers[1], •Tim Lappe[1], and Johann Kroha[1,2] — [1]Physikalisches Institut and Bethe Center for Theoretical Physics, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Center for Correlated Matter, Zhejiang University, Hangzhou, Zhejiang 310058, China

Bose-Einstein condensation of light was first realized in 2010 by filling a photon gas into a dye-filled optical microcavity and subsequently thermalizing it at room temperature. Recently, mirror delamination has enabled the creation of double-well potentials for the photons, such that Rabi or Josephson oscillations can be observed. For short reabsorption times of the photons by the dye, these undergo a collapse and revival. We describe this effect in terms of the non-Markovian dynamics of the bath of dye-molecule excitations. To study the nonequilibrium dynamics, we use the Keldysh technique in a path-integral formulation. The dye molecule excitations are modeled by a miniband of bosonic excitations, which is a good approximation for the realistic case of low excitation density. We take into account cavity losses as well as nonradiative decay and transverse dephasing in the dye. We find a crossover from a regime of normal Josephson oscillations to collapse-and-revival dynamics, depending on system parameters like the cavity cutoff and the photon-dye coupling. This illuminates the physically important processes that are responsible for collapse and revival in the system.

Q 38.5 Tue 16:15 Orangerie

Kinetic theory of non-thermal fixed points in a Bose gas — •Aleksandr Mikheev, Christian-Marcel Schmied, Isara Chantesana, and Thomas Gasenzer — Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany

We outline a kinetic theory of non-thermal fixed points for the example of a dilute Bose gas. We study universal dynamics after a cooling quench, focusing on situations where the time evolution represents a pure rescaling of spatial correlations, with time defining the scale parameter. Possible universal dynamics is identified by means of a scaling analysis of the kinetic equation describing the interactions of (quasi)particle field modes. The non-equilibrium initial condition set by the quench induces a redistribution of particles in momentum space. This can take the form of a wave-turbulent flux or more general evolution in which the momentum distribution shifts in a self-similar manner, signaling the critically slowed approach of a non-thermal fixed point. The approach of the fixed point is tied to collective scattering between highly occupied long-wavelength modes which require a description in terms of a non-perturbative kinetic theory. We obtain a possible finite-size interpretation of wave-turbulent scaling recently measured by Navon et al. [N. Navon, A. L. Gaunt, R. P. Smith, and Z. Hadzibabic, *Nature 539, 72 (2016)*].

Q 38.6 Tue 16:15 Orangerie

Melting of Mott Lobes of Bosons in an Optical Lattice — •Martin Bonkhoff, Oliver Thomas, Axel Pelster, Herwig Ott, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

We investigate the finite-temperature properties of harmonically confined bosons in a 3d cubic optical lattice. At first we solve numerically exact the underlying Bose-Hubbard model in mean-field approximation, where we take into account the harmonic trapping confinement via the local density approximation. With this we obtain the quantum phase diagram as well as the particle and the entropy density, which reveal that the Mott lobes melt due to a delicate interplay of thermal fluctuations [1] and particle hopping. Finally, we compare the theoretical calculations for the resulting particle density with experimental measurements, which were obtained with a scanning electron microscope [2].

[1] F. Gerbier, Phys. Rev. Lett. **99**, 120405 (2007)
[2] B. Santra and H. Ott, J. Phys. B **48**, 122001 (2015)

Q 38.7 Tue 16:15 Orangerie

Quantum field mapping of dissipative quantum systems — •Etienne Wamba, Axel Pelster, and James Anglin — Technische Universität Kaiserslautern, 67663, Kaiserslautern, Germany

We consider an arbitrary D-dimensional quantum gas that interacts with a bath. In an attempt to recover the Lindblad master equation and generalize the Caldeira-Leggett model, we describe the entire-system dynamics as that of a quantum gas that is made of two species of particles, using a single Hamiltonian. We exactly map into each other, the quantum fields of different evolutions of the set, and for some specific types of coupling between them, we try to solve the evolution of the quantum fields of the systems.

Q 38.8 Tue 16:15 Orangerie

Self organisation of a BEC in two crossed cavities across an atomic resonance — •Davide Dreon, Andrea Morales, Philip Zupancic, Xiangliang Li, Tobias Donner, and Tilman Esslinger — ETH, Zürich, Switzerland

The interaction of a Bose-Einstein condensate (BEC) with the electromagnetic field of an optical cavity is known to exhibit a superradiant phase transition to a self-organized phase. In our experiment, a ^{87}Rb BEC is placed at the mode crossing of two optical cavities. The BEC is illuminated with a 'pump' laser beam whose detuning from the D_2 atomic line determines the interaction regime. We recently explored different red detunings, where the system reduces its potential energy spontaneously forming an attractive lattice in the cavity mode. Here, we have observed a supersolid phase [1,2] and a phase with intertwined order [3]. In contrast, in the blue detuned case the energy of the atoms is increased by the presence of an optical lattice and therefore spontaneous superradiant scattering in the cavity should be inhibited.

I will report on our most recent experimental results on the blue side of the atomic resonance, where we observe, surprisingly, that self-organization is still possible. We measure the phase diagram of the system and explain our findings with simple energy arguments. In addition to the steady state regime typical of red detunings, dynamical instabilities leading to limit cycles of the cavity field amplitude or chaotic behaviors are expected [4].

[1] Nature, 543, 87-90 (2017), [2] arXiv:1704.05803 (to appear in Science), [3] arXiv:1711.07988, [4] PRL 115, 163601 (2015)

Q 38.9 Tue 16:15 Orangerie

Coupled order parameters with ultracold atoms in two crossed cavities — •Philip Zupancic[1], Andrea Morales[1], Julian Léonard[1,2], Xiangliang Li[1], Davide Dreon[1], Tilman Esslinger[1], and Tobias Donner[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

The concept of intertwined order describes the simultaneous existence of independent order parameters and can therefore allow materials to feature multiple properties. Examples include multiferroic materials that have coexisting ferroelectric and ferromagnetic orders leading to enhanced functionalities, and materials that are superconducting at high temperatures due to intertwining between charge- and spin-order.

I will report on our recent experimental realization of an intertwined ordered phase in a quantum gas where we can control the interaction between the atoms at the microscopic level. Our system is realized by a BEC that can transit into self-organized phases with the modes of two crossed optical cavities.

For vanishing inter-order coupling we realize a supersolid phase of matter by symmetry enhancement of the composite order parameter to a $U(1)$ symmetry. Here we observe the simultaneous existence of a Higgs and Goldstone mode. Increasing the inter-order coupling, this symmetry breaks down to a $\mathbb{Z}_2 \times \mathbb{Z}_2$, and we observe the emergence of an extended intertwined phase arising from the coupling of the individual order parameters. This coupling enables us to increase or decrease the critical point of one order by controlling the other.

Q 38.10 Tue 16:15 Orangerie

Superfluidity and Vortex interactions in 2D Bose mixtures — •Volker Karle — Institut für Theoretische Physik, Universität Heidelberg, D-69120 Heidelberg

Two-component Bose mixtures in low dimensions are at the center of the current interest in Bose droplets. We theoretically consider a two-component bosonic gas in two dimensions at low temperatures with zero-range repulsive interaction. While mapping the classical binary liquid to an Ising-like model provides corrections to the mean-field densities, in 2D another phenomenon appears: The non-dissipative drag, also called Andreev-Bashkin effect, leads to a modification of the usual BKT-transition for the coexistence phase where both components exhibit superfluid behavior at the same time. We study the renormalization of the densities at finite temperatures using standard RG-methods.

Q 38.11 Tue 16:15 Orangerie

Variable potentials for thermalized light and coupled condensates — •David Dung[1], Christian Kurtscheid[1], Julian Schmitt[2], Tobias Damm[1], Frank Vewinger[1], Jan Klärs[3], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn — [2]present address: Department of Physics, University of Cambridge, United Kingdom — [3]present address: Faculty of Science and Technology, University of Twente, The Netherlands

Cold atoms in lattice potentials are an attractive platform to simulate phenomena known from solid state theory, as the Mott-insulator transition. In contrast, the field of photonics usually deals with non-equilibrium physics. Recent advances towards photonic equilibrium physics include polariton lattice experiments, as well as the demonstration of a photon condensate in a dye-filled microcavity. Here we report the creation of variable micropotentials for light using thermo-optic imprinting within a supermirror microcavity filled with a dye-polymer solution. The long photon lifetime allows for the thermalization of photons in microsites. Within the generated trapping potentials, photons by repeated absorption-emission cycles thermalize to the temperature of the dye solution, and in a single microsite we observe a photon Bose-Einstein microcondensate. Effective interactions between the otherwise nearly non-interacting photons are observed due to thermooptic effects, and in a double-well system tunnel coupling between sites is demonstrated, as well as the hybridization of eigenstates. Prospects of the findings include photonic lattices in which cooling alone can produce entangled manybody states.

Q 38.12 Tue 16:15 Orangerie

Weakly interacting Bose gases far from thermal equilibrium — •Lingna Wu, André Eckardt, and Alexander Schnell — Max Planck Institut für Physik komplexer Systeme

For the ideal gas a simple description of this open system is given by the Born-Markov approximation. Within this framework, the bath induces quantum jumps between energy eigenstates. Taking into account temperature-dependent dissipation for the interacting gas is challenging. Already on the level of a simple mean field approximation, it requires the diagonalization of the mean field Hamiltonian in every step of the time integration. We propose and test a scheme to circumvent this problem by treating the system-bath coupling semi-classically. This allows for simulating true non-equilibrium steady states, for example by coupling the system to two baths with different temperature T. We treat both systems with particle number conservation and systems with particle pump and loss. In the latter case we apply our model to find predictions for exciton polariton experiments.

Q 38.13 Tue 16:15 Orangerie

Geometric Phase for Gaussian Unitaries — •Stephan Kleinert, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm

In the presence of a time-dependent Hamiltonian, a quantum state accumulates, apart from a dynamical phase, a geometric phase which solely depends on the topology of the projective Hilbert space.

We investigate the geometric phase acquired by an arbitrary quantum state (pure and mixed states) in the presence of a general quadratic Hamiltonian. To address this problem, we use the powerful tool of Gaussian unitaries providing a simple interpretation in Wigner phase space. In this context, we further introduce the notion of geometric phase in symplectic continuous-variable phase space.

As an example, our general formalism is applied to motional states in light-pulse atom interferometers [1].

The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economics and Energy (BMWi) under grant number 50WM1556.

[1] S. Kleinert, et al., *Representation-free description of light-pulse atom interferometry including non-inertial effects*, Physics Reports **605**, 1 (2015).

Q 38.14 Tue 16:15 Orangerie

Diffractive Guiding of Matter Waves — •Moritz Carmesin[1], Maxim A. Efremov[1], Dror Weisman[2], Ady Arie[2], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, 89069 Ulm, Germany — [2]Department of Physical Electronics, Faculty of Engineering, Tel-Aviv University, Tel-Aviv 69978, Israel — [3]Hagler Institute for Advanced Study, Institute for Quantum Science and Engineering (IQSE), and Texas A&M AgriLife Research, Texas A&M University, College Station, TX 77843-4242, USA

A matter wave freely propagating behind a single slit narrows before it expands. This effect, known as diffractive focusing [1, 2], originates exclusively from the modulation of the wave's amplitude, rather than from the phase modulation due to a lens.

By placing several single slits in a row, we can exploit their narrowing feature in order to guide a wave, i. e. to transfer a maximal amount of intensity to a point at a given distance from the source of the wave. This novel kind of wave guide based on diffraction is useful in situations where the conventional guiding based on reflection is not easily applicable.

This work is supported by the German-Israeli Cooperation (DIP) of DFG.

[1] Case, W. B., Sadurni, E., Schleich, W. P., Optics Express **20**, 27253 (2012)

[2] Weisman, D. et al. PRL **118** 154301 (2017)

Q 38.15 Tue 16:15 Orangerie

Impact of interactions on BEC interferometry — •Christian Ufrecht, Albert Roura, Wolfgang P. Schleich, and the QUANTUS team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm

In recent years, light-pulse atom interferometry with macroscopic arm separation and Bose-Einstein condensates as highly coherent atom sources has attracted a lot of attention. However, interactions between the atoms, which are often disregarded in the theoretical description, can lead to significant effects such as mean-field phase shifts or phase diffusion.

To better understand these phenomena, we discuss the problem in second quantization, where the inclusion of interactions is straightforward. Based on a clear separation of the atomic clouds along different paths in position or momentum space, we propose a method that leads to a path-dependent description involving a transformation to the rest frame for each individual path. In this picture phase contributions predicted by the non-interacting theory and effects generated by the interaction separate most clearly. As an application of this method we discuss how two-mode squeezing between momentum states driven by atomic interactions can be exploited to overcome the shot-noise limit.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1556 (QUANTUS IV).

Q 38.16 Tue 16:15 Orangerie

Wigner representation of Bose-Einstein condensates in the Thomas-Fermi limit — •Jan Teske and Reinhold Walser — Technische Universität Darmstadt

In 2017, the MAIUS sounding rocket created the first Bose-Einstein condensate in space and realised a matter-wave interferometer [1]. In general, atom interferometers serve as high precision sensors for accelerations, gravity and gravity gradients with a wide range of scientific and technological applications.

Simulating cold quantum gases is mostly done with classical mean fields or with ray tracing simulations in phase space. It is therefore necessary to have simple approximation schemes for interacting BECs in the Thomas-Fermi limit in phase space. In the present contribution, we compare analytical approximation for the Thomas-Fermi Wigner functions with a full Gross-Pitaevskii mean field simulation.

[1] http://www.dlr.de/dlr/desktopdefault.aspx/tabid-10081/151_read-20337/

Q 38.17 Tue 16:15 Orangerie

Interplay between AC-Stark shift and two-photon light shift in Raman diffraction — •Eric P. Glasbrenner[1], Alexander Friedrich[1], Wolfgang P. Schleich[1], Ernst M. Rasel[2], and Enno Giese[3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm — [2]Institut für Quantenoptik, Leibniz Universität Hannover, D-30167 Hannover — [3]Department of Physics, University of Ottawa, K1N6N5 Ottawa

Light-pulse atom interferometry has become a standard tool for the realization of high precision experiments and in quantum sensing applications as well as tests of fundamental physics. Nowadays such interferometers rely on either Raman or Bragg diffraction, realized via a retro-reflective setup with two counter-propagating lasers. However setups of this kind lead to a light shift contribution to the interferometer phase due to the off-resonant two-photon transitions. The AC-Stark shift on the other hand arises naturally as the atoms interact with two counter-propagating Raman beams. Usually, this AC-Stark shift is only considered as an energy shift of the initial atomic levels [PRA 78 043615 (2008)] without any contribution to dynamical effects such as the light shift. However, in our presentation we show this point of view is wrong and find the explicit modifications to the light shift due to the AC-Stark effect and analyze its consequences. The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1556.

Q 38.18 Tue 16:15 Orangerie

Optimal focusing of free matter waves — •Patrick B. Boegel[1], Maxim A. Efremov[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm — [2]Institute for Quantum Science and Engineering (IQSE), Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843

A common way to control the position and the size of maximal focusing of a matter-wave is to use a lens, which imprints a position-dependent phase on the initial wave. However, even quantum mechanics allows focusing even without [1,2] a lens, that is when the initial wave function is a real-valued one. Hence, the optimal focusing relies on a smart choice of this initial wave function [3].

Here we find the optimal real-valued wave function of a free particle for the case of two dimensions and study the role of anti-centrifugel forces [4] in matter-wave focusing.

[1] Case, W.B.; Sadurni, E.; Schleich, W.P., Optics Express 20, 27253 (2012)

[2] Weisman D. et al. Phys. Rev. Lett. **118**, 154301 (2017)

[3] Vogel, K. et al., Chem. Phys. **375**, 133-143 (2010)

[4] Białynicki-Birula I., et al., Phys. Rev. Lett. **89**, 060404 (2002)

Q 38.19 Tue 16:15 Orangerie

Electron beam splitter in microwave fields — Robert Zimmermann, Philipp Weber, •Michael Seidling, and Peter Hommelhoff — Lehrstuhl für Laserphysik (FAU), Staudtstraße 1, 91058, Erlangen, Germany

We report on the development of an electron beam splitter based on free electrons manipulated by microwave electric fields applied to micro-structured chips. The working principle is of a Paul trap: a microwave potential applied to electrodes causes an oscillating electric field by which electrons can be guided in a pseudopotential [1]. The transverse confinement naturally provides discretized motional quantum states that govern the motion. Based on the initial designs of guides [2-4], we have developed an electron beam splitter, which is predicted to split coherently. We show ongoing efforts to demonstrate coherent splitting: electron optics are integrated into the setup to overlap both output beams and make interference stripes visible. To establish phase control over the electron and the microwave, a laser triggered SEM is used as a pulsed electron source. The future goal is to show interaction-free measurements [5] with free electrons, which would pave the way for the development of the quantum electron microscope [6].

[1] W. Paul, Rev. Mod. Phys. 62, 531 (1990) [2] J. Hoffrogge, et al.; Phys. Rev. Lett. 106, 193001 (2011) [3] J. Hoffrogge and P. Hommelhoff; New J. Phys. 13, 095012 (2011) [4] J. Hammer, et al.; Phys. Rev. Lett. 114, 254801 (2015) [5] P. Kwiat, et al.; Phys. Rev. Lett. 74, 4763 (1995) [6] W. P. Putnam and M. F. Yanik; Phys. Rev. A 80, 040902(R) (2009)

Q 38.20 Tue 16:15 Orangerie

Qualification of a lasersystem for atom interferometry

with Potassium — •Julien Kluge[1], Julia Pahl[1], Aline N. Dinkelaker[1], Christoph Grzeschik[1], Markus Krutzik[1], Achim Peters[1,2], and The QUANTUS Team[1,3,4,5,6,7] — [1]HU Berlin — [2]FBH Berlin — [3]U Bremen — [4]LU Hannover — [5]JGU Mainz — [6]U Ulm — [7]TU Darmstadt

The QUANTUS-2 experiment is a testbed for dual-species atom interferometry in microgravity with potassium and rubidium inside a drop tower. While the rubidium system is already running and performing in atom-chip based BEC experiments, the potassium subsystem is coming towards its final assembly and integration.

In this poster, we present the controling mechanisms for the potassium laser system. This includes the software for the hardware communication to regulate multiple experimental parameters and handling of incoming and outgoing data streams. One main feature is a verification of an automated frequency stabilization using atomic spectroscopy for the DFB diode lasers and a evolutionary algorithm-based optimization of TEC feedback parameters.

Furthermore we show verification and qualification tests done on a miniaturized drop tower as well as results gathered in the recent campaigns.

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 50WM1555

Q 39: Poster: Quantum Optics and Photonics II

Time: Tuesday 16:15–18:15 Location: Zelt Ost

Q 39.1 Tue 16:15 Zelt Ost

Rydberg quantum optics in ultracold gases — •Nina Stiesdal, Christoph Braun, Philipp Lunt, Simon Ball, Christoph Tresp, and Sebastian Hofferberth — Department of Physics, Chemistry and Pharmacy, SDU, Campusvej 55, 5230 Odense M, Denmark

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons enables the realization of optical nonlinearities which can modify light on the level of individual photons. This approach forms the basis of a growing Rydberg quantum optics toolbox, which already contains photonic logic building-blocks such as single-photon sources, switches, transistors, and conditional pi-phase shifts [1].

Following our relocation from Universität Stuttgart to University of Southern Denmark, Odense, we present the new iteration of our experimental apparatus. We also present the recent demonstration of strong coherent interaction between a few-photon probe field and an effective two-level Rydberg 'superatom' [2]. We further introduce our steps towards the formation of two such superatoms.

We discuss how the interference between the possible storage paths in Rydberg atoms and molecules affects the efficiency of storing and retrieving photons [3], and present our investigation of photon subtraction by many-body decoherence [4].

[1] O. Firstenberg et. al., J. Phys. B 49, 152003 (2016)
[2] A. Paris-Mandoki et. al., Phys. Rev. X 7, 41010 (2017)
[3] I. Mirgorodskiy et. al., Phys. Rev. A 69, 011402 (2017)
[4] C. R. Murray et. al., arXiv:1710.10047v1 (2017)

Q 39.2 Tue 16:15 Zelt Ost

Quantum imaging with incoherently scattered light from a free-electron laser — •Raimund Schneider — Universität Erlangen-Nürnberg — Erlangen Graduate School in Advanced Optical Technologies

We report on a new method to reconstruct an unknown geometry of light sources using higher order spatial intensity correlations. Our imaging protocol allows the extraction of structural information from the light scattered by a source distribution even though the sources emit completely incoherently. The imaging method is of particular interest in the X-ray regime where coherence is easily lost, e.g., due to imperfect beam optics or incoherent scattering processes. We present experimental results of imaging a hexagonal source arrangement mimicking a benzene molecule. In the experiment the atoms are simulated by holes in a SiN membrane illuminated with the incoherent light scattered from a diffusor which itself is irradiated by the beam of the FLASH free electron laser at DESY, Hamburg.

Q 39.3 Tue 16:15 Zelt Ost

Time multiplexed photonic quantum walks with 4D coins — •Lennart Lorz[1], Sonja Barkhofen[1], Evan Meyer-Scott[1], Thomas Nitsche[1], Václav Potocek[2], Igor Jex[2], and Christine Silberhorn[1] — [1]Applied Physics, University of Paderborn, Warburger Strasse 100, 33098 Paderborn, Germany — [2]Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Brehová 7, 115 19 Praha, Czech Republic

Discrete time quantum walks, realized in time multiplexed architecture, are an established tool to experimentally study quantum transport phenomena. We implemented a photonic quantum walk on a looped Michelson interferometer in contrast to the standard Mach-Zehnder setup to investigate the benefits of a new interferometric geometry. By exploiting the two different traveling directions in the loop in addition to the two possible polarizations of the walker we establish a four dimensional coin space for one spatial dimension. A new key feature is the possibility to implement a quantum walk on a circle allowing for the experimental simulation of dynamics with periodic boundary conditions. We will present our new setup, its theoretical modeling, experimental results and future applications.

Q 39.4 Tue 16:15 Zelt Ost

Controlled optical transport of cold atoms into a hollow-core fiber — •Ronja Wirtz, Maria Langbecker, Mohammad Noaman, Wei Li, Parvez Islam, and Patrick Windpassinger — Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Cold atoms inside hollow-core fibers are a promising candidate for a well defined atom-light interface. To obtain high control over the system, the characterization of the interactions between atoms and the fiber wall is required. Here, one essential part is an efficient and well controlled transport of the atoms inside the fiber. By this, both spatial and temporal distribution of the atoms can be manipulated.

In our experimental setup, laser cooled Rubidium atoms are transported into a hollow-core fiber using an optical conveyor belt. This poster explains the details of optimizing our transport procedure both for moving the atoms outside and inside the fiber. We are applying different types of acceleration ramps to vary the transport process. Additionally power ramps of the trapping beams are implemented to reduce heating of the atoms caused by the two counterpropagating dipole trap beams. This technique is an important ingredient to investigate properties of Rydberg atoms inside hollow-core fibers [1].

[1] M. Langbecker, M. Noaman, N. Kjaergaard, F. Benabid, and P. Windpassinger, Phys. Rev A 96, 041402(R) (2017).

Q 39.5 Tue 16:15 Zelt Ost

Microtrap for hybrid Rb-Yb$^+$ systems — •Abasalt Bahrami[1], Matthias Müller[1], Jannis Joger[2], Rene Gerritsma[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz — [2]Institute of Physics, Universiteit van Amsterdam

Trapped ions represent a highly controllable quantum system with strong long-range repulsive Coulomb interactions [1]. Laser cooled ions are spatially localised, they can be individually detected and allow for investigating local properties of a cold atomic sample [2]. In order to combine laser cooled ions and atoms in a single experimental setup, we have designed and fabricated a hybrid atom-ion trap based on modern chip trap technology [3]. Here, we report trapping of Yb$^+$ in this device. We plan loading ^{87}Rb atoms into mirror-MOT [4], eventually a magnetic chip trap. We report applications for studies of cold chemistry, cold collisions, and polaron physics.

[1] W. Paul, Rev. Mod. Phys. 62, 531 (1990). [2] A. Härter, J. Hecker Denschlag, Cont. Phys., 55, 33 (2014). [3] J. Joger, Master thesis, University of Mainz (2013). [4] J. Reichel, W. Hänsel, T. W. Hänsch, Phys. Rev. Lett. 83, 3398 (1999).

Q 39.6 Tue 16:15 Zelt Ost

Manipulation by four-photon Hong-Ou-Mandel interference — •Alessandro Ferreri, Vahid Ansari, Polina Sharapova, Christine Silberhorn, and Torsten Meier — Department of Physics and CeOPP, University of Paderborn, Warburger Strasse 100, D- 33098 Paderborn, Germany

Multiphoton quantum interference recently is in focus of research because of its possibility to extended the basis of encoding information and to improve the precision of phase measurement. Moreover multiphoton quantum interference plays significant role in quantum information science and allows investigating mesoscopic effects. In this work we focused on the Hong-Ou-Mandel (HOM) interference by involving four photons generated in KTP. Photons are created by using a type-II Parametric Down Conversion (PDC) source. By manipulation of Joint Spectral Amplitude (JSA) it is possible to change significantly the HOM-dip profile. Here we consider different shapes of JSA by increasing the laser pulse duration; different values of BS parameter (50/50 and unbalanced); different laser profile, by considering a Gaussian profile or first order Hermite-Gaussian pump laser. Our system was studied both theoretically and experimentally. We show that HOM interference profile depends on the number of Schmidt modes of PDC light and can be manipulated by laser pulse duration. We observed that by increasing the number of modes a raising of HOM dip/peak in the coincidence probability. By using BS parameters it is possible to manipulate the visibility of HOM interference. Theoretical simulations are in good agreement with the experimental results.

Q 39.7 Tue 16:15 Zelt Ost

Single Silicon-Vacancy centre with improved spectral stability in nanodiamonds — •Ou Wang[1], Lachlan Rogers[2], Andrea Filipovski[1], Valery Davydov[4], Viatcheslav Agafonov[3], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Ulm Universität, Ulm, Deutschland — [2]Department of Physics and Astronomy, Macquarie University, Sydney, Australia — [3]Institute for High Pressure Physics, Russian Academy of Science, Moscow, Russia — [4]Greman, Universit F. Rabelais, Tours, France

With appealing properties, weak side band and mostly polarized fluorescence, silicon vacancy centers (SiVs) in diamonds have became a promising system for the realization of bright, narrow bandwidth, single-photon sources. In bulk diamond at cryogenic temperatures the SiV ZPL has been observed with a linewidth limited only by fluorescence lifetime, and the transitions were spectrally stable over hours.Unfortunately the spin coherence time was found to be severely limited by phonon processes in the ground state, which may be quenched in small nanodiamonds (NDs).

However, intermittencies in luminescence, as well as significant spectral diffusion were found when investigating SiV in NDs. With surface treatment, we have improved the optical stability of SiV in NDs and gained access to single SiVs in NDs. The spectroscopical measurements on SiV ZPL fine structures showed a wide distribution of tranversial strain in NDs, with which we took a glimpse into the SiV strain model. The possibility of finding bulk-like low strained SiV offered new paths of acquiring indistiguishable photon emissions by SiV in NDs.

Q 39.8 Tue 16:15 Zelt Ost

Surface-Electrode Trap to Control Levitating Nano-diamonds — •Deviprasath Palani, Oleg Orlov, Tobias Schaetz, and Ulrich Warring — Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany

Physical properties of crystal defects, e.g., nitrogen-vacancy (NV) centers, in synthetic diamonds are intensively studied, as they rise the promise for several applications within the fields of physics, nanotechnology, and life science [1]. As the quantum nature (coherence) of NV centers is well protected by the surrounding diamond lattice, it can be harnessed even under ambient conditions. To use these defects as nanoscale sensors, they are packed into diamond crystallites of a few tens of nanometers in diameter comprised of about 10^9 carbon atoms. But to harness their full potential, suitable techniques are required to control their spatial position and orientation, as well as, to efficiently manipulate their quantum state. In our presentation, we introduce details of a compact and robust experimental setup that builds on a so-called surface-electrode trap [2], originally developed for trapping individual atoms [2]. Our setup integrates components necessary to control all degrees of freedom(as mentioned above) in a commercially fabricated printed circuit board. We present preliminary benchmark results and discuss application prospects. [1] Schirhagl, R. et al., Annual Review of Physical Chemistry. 2014 Apr;65(1):83*105. [2] Seidelin, S. et al., Phys. Rev. Lett. 96, 253003 (2006).

Q 39.9 Tue 16:15 Zelt Ost

Iterative Time Ordering for Optimal Control of Open Quantum Systems — •Lutz Marder and Christiane P. Koch — Institut für Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel (Germany)

An explicit time-dependence of the Hamiltonian, for example due to an external driving field, introduces an additional challenge for dynamical simulations. The most commonly used propagation approaches usually rely on dividing the overall propagation time into small steps, in which the time-dependence of the Hamiltonian is approximately constant and the time evolution operator becomes a matrix exponential. This inevitably introduces inaccuracies due to neglection of time ordering. In contrast, the iterative time ordering (ITO) approach allows to fully account for any explicit time-dependence of the Hamiltonian. It was originally constructed for numerically exact propagation in Hilbert space for state vectors. Here, we generalize it to density matrices and use the driven quantum harmonic oscillator for benchmarking. Furthermore we discuss the combination of this algorithm with quantum optimal control theory and apply it to a strongly driven superconducting circuit.

Q 39.10 Tue 16:15 Zelt Ost

Enhancing superradiance at a distance through motional states — •Martin Korzeczek and Daniel Braun — University Tübingen - Institute for theoretical Physics, Tübingen

Superradiance from atomic clouds is usually only observed if the atomic distances are much smaller or comparable to the wavelength of the atomic transition. Here, we investigate to what extent superradiance can be modified by engineering the motion of the atoms. For negligibly close atoms, the motion can only decrease the superradiance. We show that for atoms that are far away from each other (distances much larger than the wavelength) superradiance can be retained to a certain degree by carefully designing the motional states. We determine the upper bounds of the enhancement compared to the motionless states and give examples for motional states that enable such a relative enhancement for atoms at distances comparable to the wavelength of the emitted light.

Q 39.11 Tue 16:15 Zelt Ost

Nanoscale Manipulation of Nanodiamonds — •Konstantin Fehler[1,2], Lukas Hartung[2], Andrea Filipovski[2], Yan Liu[2], Ou Wang[2], Alexander Kubanek[1,2], and Fedor Jelezko[1,2] — [1]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [2]Institute for Qunatum Optics, Ulm University, D-89081 Ulm

Nanoscale manipulation of nanodiamonds opens new perspectives for building hybrid quantum systems. One and two dimensional spatial positioning, dipole alignment, decomposition of nanodiamond clusters and pick and drop of nanodiamonds are among the main challenges. The recently shown bulk like properties of SiV in nanodiamonds [1], like almost fourier limited linewidths and low strain, together with the creation of single quantum emitters per nanodiamond enable to build future hybrid quantum systems.

[1] Jantzen U et al., 2016 New J. Phys. 18 073036

Q 39.12 Tue 16:15 Zelt Ost

Gearing nanodiamonds towards quantum optical applications — •Lukas Hartung[1], Konstantin Fehler[1,2], Stefan Häussler[1,2], Ou Wang[1], Andrea B. Filipovski[1], Fedor Jelezko[1,2], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, D-89081 — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, D-89081 Ulm

Recent experiments have demonstrated SiV^- centers in low-strain nanodiamonds with narrow optical transitions, almost fourier-limited lines and a good polarization contrast [2]. Together with a narrow inhomogeneous distribution of optical tranistions SiV^- nanodiamonds offer potential for the creation of indistinguishable photons from distinct emitters. Furthermore, SiV^- nanodiamonds open up new perspectives for prolonged spin coherence times T_1 [1,2]. These properties make SiV nanodiamonds a promising candidate for quantum optical applications consisting of many connected quantum systems, like quantum repeaters.

[1] Uwe Jantzen et al. 2016 New J. Phys. 18 073036
[2] Lachlan J. Rogers et al. (in preparation)

Q 39.13 Tue 16:15 Zelt Ost

SiRypY: Strongly interacting Rydberg polaritons in Yt-

terbium — •Simon Ball, Nina Stiesdal, Christoph Braun, Christoph Tresp, Philip Lunt, and Sebastian Hofferberth — Department of Physics, Chemistry and Pharmacy, SDU, Campusvej, 55230 Odense M, Denmark

We study non-linear quantum optics by reversibly mapping the strong inter-atomic interactions between Rydberg excitations onto single optical photons [1]. A key figure of merit for such experiments is the optical depth per Rydberg blockade volume optimised by achieving high atomic densities. However, at high atomic densities, Rydberg-ground-state collisions become a limiting factor with the commonly used alkali elements [2].

Here we discuss the development of a new experiment designed to study the interactions between a large number of Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density [3]. It is proposed to overcome the atomic density limitations through the use of Ytterbium, an alkaline-earth-like element without a p-wave resonance between the Rydberg electron and surrounding ground state atoms [4].

[1] Firstenberg et al, J. Phys. B 49, 152003 (2016)
[2] Balewski et al, Nature 502, 664 (2013)
[3] Jachymski et al, Phys. Rev. Lett. 117, 053601 (2016)
[4] Camargo et al, Phys. Rev. A 93, 022702 (2016)

Q 39.14 Tue 16:15 Zelt Ost

Towards practical integrated Quantum Pulse Gate devices — •Jano Gil López, Matteo Santandrea, Nicola Montaut, John Donohue, Vahid Ansari, Markus Allgaier, Harald Herrmann, Raimund Ricken, and Christine Silberhorn — Universit\"{a}t Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098

Nonlinear wave-mixing allows for frequency conversion, bandwidth manipulation and temporal-mode selective operations such as Quantum Pulse Gates (QPGs). Such processes have many applications in photonic networks, both classical and quantum. These processes can be engineered in integrated optical devices in nonlinear materials to increase the efficiency, ease the alignment and reduce the footprint.

The conditions needed for single-mode waveguiding vary drastically between different wavelengths. To support all the fields interacting simultaneously in wave-mixing processes, significant engineering is required. Waveguide inhomogeneities and fabrication defects, which degrade the process fidelity, must also be surpassed. To overcome these issues and increase the efficiencies we investigate the use of on-chip tapers, bendings and dichroic couplers in Lithium Niobate waveguides. The goal is to produce efficient integrated wave-mixing devices (with a focus on QPGs), reducing the footprint and the need for bulk optics while allowing for complex interactions and processes.

Q 39.15 Tue 16:15 Zelt Ost

Temporal-mode selective purification and manipulation of multimode quantum light — Vahid Ansari[1], •John Matthew Donohue[1], Markus Allgaier[1], Linda Sansoni[1], Benjamin Brecht[1,2], Jonathan Roslund[3], Nicolas Treps[3], Georg Harder[1], and Christine Silberhorn[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]Clarendon Laboratory, University of Oxford, Oxford OX1 3PU, United Kingdom — [3]Laboratoire Kastler Brossel, UPMC-Sorbonne Universités, 75252 Paris, France

In order to fully exploit the time-frequency degree of freedom for photonic quantum information science, it is necessary to develop and demonstrate techniques which can manipulate the temporal structure of multimode quantum light without introducing excess noise. In this work, we experimentally demonstrate such a technique using shaped ultrafast pulses and dispersion-engineered frequency conversion as a quantum pulse gate. We controllably select broadband field-orthogonal (i.e. intensity overlapping) modes out of a multimode downconverted photon state, converting the specified mode from the infrared to the visible regime while leaving the unselected modes unaffected. Through photon-number correlation measurements, we show that such a technique selects a single mode with high purity (above 95%) and low noise (SNRs above 70). We also show through the photon-number correlations that our device can be used to both purify and redistribute the coefficients of a multimode photon state.

Q 39.16 Tue 16:15 Zelt Ost

Towards a near-unity-β laser — •Luis Morales-Inostroza[1], Xiao-Liu Chu[1], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich Alexander University, 91058 Erlangen, Germany

Fluidic dye lasers were first developed in 1966 and are still useful optical devices due in part to their wide bandwidth which makes large wavelength tunability and short pulse generation possible. More recently, miniaturization of fluidic dye lasers has emerged as a powerful option for integration of coherent light sources on a lab-on-a-chip device. Despite efforts by several groups, realization of room-temperature chip-based dye lasers with low threshold still remains a challenge. In this work, we introduce a new approach based on flowing a highly concentrated dye solution through a planar optical antenna. With our current design, we will be able to collect 99% of the spontaneously emitted photons [1,2] into the lasing mode of a cavity formed by an external mirror and the antenna. Based on our high collection efficiency, we expect to achieve a high coupling efficiency ($\beta = 1$) and low laser threshold.

Q 39.17 Tue 16:15 Zelt Ost

double transverse wavevector correlations in photon pairs generated by spdc pumped by bessel-gauss beams — verónica vicuña hernández[1], •josé tomás santiago[2], yasser jerónimo moreno[3], roberto ramírez alarcón[4], héctor cruz ramirez[1], alfred barry u'ren[1], and rocio jáuregui renaud[3] — [1]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Apartado Postal 70-543, 04510 Ciudad de México, México — [2]Max-Planck-Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [3]Instituto de Física, Universidad Nacional Autónoma de México, Apartado Postal 20-364, 01000 Ciudad de México, México — [4]Centro de Investigaciones en Optica, Loma del Bosque 115, Colonia Lomas del Campestre, 37150 León Guanajuato, México

In this work we present an experimental study of type I, frequency degenerate spontaneous parametric down conversion (SPDC) pumped by Bessel Gauss beams. Generating these beams either in the paraxial or nonparaxial regime, we studied their effects on the angular spectrum (AS), on the conditional angular spectrum (CAS) of signal-mode single photons as heralded by the detection of an idler photon, and on the transverse wavevector correlations (TWC). Our measurements show that while the pump is made nonparaxial, the AS acquires a non-concentric double-cone structure, and the CAS shape becomes dependent on the azimuthal location of the heralding detector, while the signal-idler wavevector correlation splits into doublet stripes, contrasting with the case of single-stripe when the pump is Gaussian.

Q 39.18 Tue 16:15 Zelt Ost

Quantum Optics in Mercury-filled Hollow-core Photonic Crystal Fibers — •Ömer Bayraktar[1,2], Florian Sedlmeir[1,2], Ulrich Vogl[1,2], Nicolas Y. Joly[1,2], Gerd Leuchs[1,2,3], and Christoph Marquardt[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Erlangen, Deutschland — [2]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Deutschland — [3]Department of Physics and Max Planck Centre for Extreme and Quantum Photonics, University of Ottawa, Ottawa (ON), Canada

Light-matter interactions in gas-filled fibers facilitate the observation of large non-linear optical effects at very low optical powers, ultimately at the single-photon level.

Here, we introduce a warm vapor of Mercury into a Kagomé-style hollow-core photonic crystal fiber (HC-PCF). Due to Mercury's low reactivity, no special treatment of the fiber and no additional light fields are required to prohibit atoms sticking to the fiber walls, as it is the case for similar experiments with Alkali vapors. In earlier investigations it was shown that large optical depths can be reached in this configuration [1]. Investigating coherent light-matter interactions in this setup, we study the efficient generation of non-classical light by exploiting the self-induced transparency for optical pulses [2,3,4].

[1] U. Vogl *et al.*, Optics Express **22**, 29375 (2014).
[2] K. Watanabe *et al.*, Physical Review Letters **62**, 2257 (1989).
[3] W. Zhong *et al.*, CLEOE-IQEC 2007, 4386698.
[4] U. Vogl *et al.*, Frontiers in Optics/Laser Science 2016, FW5F.4.

Q 39.19 Tue 16:15 Zelt Ost

Coherent combination of blue-green laser diodes for direct pumped Ti:Sapphire laser power scaling — •Mario Niebuhr, Axel Heuer, and Markus Gühr — Institute for Physics and Astronomy, Uni Potsdam, Germany

Direct diode pumped solid state lasers have been an important step towards smaller, more efficient and cheaper laser sources. Ti:Sapphire systems, one of the most important sources in the ultra-short community, unfortunately need a blue-green pump not easily accessible to laser diodes (LDs). While first concepts with blue LDs have been around for some time [1], even more recent experiments with multiple, more suitable green LDs [2] show only moderate output powers.

One reason would be that single emitter LDs are limited to either high output powers and a bad beam profile or vice versa due to geometrically constraints of their structure. This problem can be resolved by coupling multiple low power LDs with a *passive coherent* scheme. It would yield good beam profiles similar to a single emitter but with scalable output power compared to an incoherent approach such as in [2]. We will show first results of coherent coupling of two green LDs with 1 W of output power each using diffractive Dammann grating structures [3] written e.g. in volume Bragg gratings. In these first experiments, the grating structures will be emulated with a spatial light modulator for flexibility.

[1] Roth et al., Optics Letters, 34, 21 (2009)
[2] Gürel et al., Optics Express, 23, 23 (2015)
[3] Dammann et al., Optics Communications, 3, 5 (1971)

Q 39.20 Tue 16:15 Zelt Ost

Improved thermo-optic dispersion formulas from SPDC and nonlinear spectral magnification — •Aron Vanselow and Sven Ramelow — Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany

The accurate knowledge of the dispersion properties of nonlinear crystals is vital for many applications in classical and quantum nonlinear optics. Here, we experimentally demonstrate a new method using spontaneous parametric down-conversion (SPDC) to accurately measure thermo-optic dispersion formulas for nonlinear crystals to extend and improve on existing relations.

Our method generates photon pairs via SPDC at birefringently phase-matched signal and idler wavelengths using 3 different pump lasers. Recording the temperature-dependent signal photon spectra using a grating spectrometer then allows for fitting the temperature-dependent dispersion relations for the signal and remarkably also for the undetected idler wavelengths. Specifically, we investigate the ordinary refractive indices n_o of undoped and 5.0 mol% MgO doped congruent lithium niobate (LN) as well as the principal refractive index of the y-axis, n_y, of flux-grown potassium titanyl phosphate (KTP).

The potential error sources of our method are analysed in detail and we demonstrate that even standard spectrometers with uncooled detectors are sufficient, making our new method robust and cost-effective. Finally, we show how our setup and the new dispersion formulas can be useful for nonlinear spectral magnification, which allows for a significant increase in resolution measuring the pump laser spectrum.

Q 39.21 Tue 16:15 Zelt Ost

Polymer waveguide fabrication with high aspect ratio by direct laser writing — •Julian Schulz[1], Christina Jörg[1], and Georg von Freymann[1,2] — [1]Physics Department and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany

Due to the robustness of topologically protected states, topology is of great interest in physics since the discovery of the quantum hall effect. To simulate, e.g., topological effects one can use structures of evanescently coupled waveguides. This is due to the fact, that the time evolution of a quantum mechanical wave function in a 2D-solid corresponds to the light intensity along the propagation direction of these waveguides.

To produce these structures, we use direct laser writing (DLW) which allows to fabricate three-dimensional objects made of polymer with a resolution of less than 1 μm. First, the inverse of these waveguide arrays is written by DLW and then infiltrated with SU8. This way, waveguides with axes curved along 3D trajectories are fabricated [1].

Up to now, these waveguide axes are always oriented normal to the substrate, i.e. along the z-direction. Therefore the lower z-resolution, due to the elongation of the writing voxel in z, is no problem. However, the maximal height of these structures is thus limited by instability. To overcome this limitation, we develop a technique to fabricate waveguides with axis parallel to the substrate. This would result in a much longer evolution of light and thus more observable physics.

[1] Jörg, et al., New J. Phys. 19, 083003 (2017).

Q 39.22 Tue 16:15 Zelt Ost

Angular dependent polarization properties of graphene on nanostructured silicon carbide — •Tim Käseberg[1,2], Johannes Dickmann[1], Mattias Kruskopf[3], Thomas Siefke[4], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Technische Universität Braunschweig, LENA Laboratory for Emerging Nanometrology, Pockelsstraße 14, 38106 Braunschweig, Germany — [3]National Institute of Standards and Metrology, 100 Bureau Drive, Stop 1070, 20899-1070, Gaithersburg, MD, United States — [4]Friedrich-Schiller-Universität Jena, Institute of Applied Physics, Albert-Einstein-Straße 15, 07745 Jena, Germany

Two-dimensional materials such as graphene have attracted recent interest in many optical and electronical applications. Particularly for nano-optical metasurfaces the use of graphene promises compact tunable devices with broad spectral bandwidth. For example, the high absorption of graphene layers can be used to realize nano-optical polarizers. In this contribution, we investigate the angular dependent polarization properties of graphene as a coating on nano-structured silicon carbide (SiC) samples. To this end, we set up a Mueller matrix polarimeter for wavelengths from 400 to 1650 nm. Further, we developed an effective medium approach to model the experimental results.

Q 39.23 Tue 16:15 Zelt Ost

Direct Laser Written Polymer Waveguides for Optical Chips — •Alexander Landowski[1,2], Stefan Guckenbiehl[1], Marius Schönberg[1], Jonas Gutsche[1], Georg v. Freymann[1,3], and Artur Widera[1,2] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schroedinger-Str. 46, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Erwin-Schroedinger-Str. 46, 67663 Kaiserslautern, Germany — [3]Fraunhofer Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern

Control over the degrees of freedom of photons in microscopic photonic structures, such as polarization, spatial mode, or orbital angular momentum, is essential for applications, e.g., quantum optical experiments on a chip.

We have recently shown direct laser written polymer waveguides fabricated from a low-fluorescent negative tone photoresist via two-photon lithography [1]. Here, we present an optimization of the waveguide's shape, minimizing losses of the propagating light. Further, we report on the current status of structures enabling manipulation of the guided light's polarization in our waveguides.

Our work opens the door to control over photonic degrees of freedom in micro-optical networks for quantum optical experiments and coupling to individual nanoemitters on photonic chips.

References: [1] A. Landowski et al., APL Photonics 2, 106102 (2017)

Q 40: Poster: Quantum Optics and Photonics III

Time: Tuesday 16:15–18:15 Location: Zelt West

Q 40.1 Tue 16:15 Zelt West

Inferring two-qubit causal structures — •Jonas Kübler and Daniel Braun — Institut für theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

The rise of quantum information theory and machine learning has led to increasing interest in causal inference in quantum mechanics. Here we study a set-up proposed by Ried et al. [Nat. Phys. 11, 414 (2015)] in which a common-cause scenario can be mixed with a cause-effect scenario, and for which it was found that quantum mechanics can bring an advantage in distinguishing the two scenarios: Whereas in classical statistics, interventions such as randomized trials are needed, a pure observational scheme is enough to detect the causal structure if initial entanglement is available.

We analyze this setup in terms of the geometry of unital positive but not completely positive qubit-maps, arising from the mixture of qubit channels and steering maps. We find the range of mixing parameters interpolating between cause-effect and common-cause that can generate given correlation by establishing new bounds on signed singular values of sums of matrices. We prove a quantum advantage in a more general setup allowing arbitrary unital channels and initial states with fully mixed reduced states. Based on the geometry, we quantify the quantum advantage depending on the observed correlations and find the number of additional constraints needed for the complete solution of the causal inference problem.

Q 40.2 Tue 16:15 Zelt West

Shannon entropy of quantum random walks — •Shahram Panahiyan[1] and Stephan Fritzsche[1,2] — [1]Helmholtz-Institut Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Germany

Recently, there has been a great interest in quantum random walk which is the counter part of the classical random walk. This interest arises from the particular properties of these walks, such as their spread which may arise quadratically faster than classical random walks, their nonclassical probability distribution. These properties make the quantum random walk promising for quantum computing and engineering quantum algorithms [1]. On the other hand, Shannon entropy has been introduced as a tool for determining the amount of uncertainty in the state of a physical system. In fact, (Shannon) entropy is a natural measure of uncertainty, perhaps even more appropriate than the standard deviation [2]. It naturally captures the amount of information about a measurement outcome. Here, we investigate the Shannon entropy of quantum random walks. Our aim is to understand the evolution of entropy as a function of: coin, initial state and steps.

[1]: S. E. Venegas-Andraca, Quant. Info. Process. 11, 1015 (2012).
[2]: P. J. Coles et al., Rev. Mod. Phys. 89, 015002 (2017).

Q 40.3 Tue 16:15 Zelt West

Multilayer ion trap for scalable quantum simulation and quantum information processing — •Giorgio Zarantonello[1,2], Henning Hahn[1,2], Sebastian Grondkowski[1], Timko Dubielzig[1], Fabian Ude[1], Martina Wahnschaffe[1,2], Amado Bautista-Salvador[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig

Based on recent advances in surface-electrode trap fabrication in our group, we present a novel trap design with embedded multi-layer waveguides to implement quantum control using the microwave near-field gradient approach [1-3]. This new multilayer trap represents a significant development from the previous generations in terms of both scalability and performance. We will present the main results from the finite element simulations of the microwave near-fields and compare it with the previous single-layer design [4]. The new room temperature experimental setup housing the trap structure will also be presented.

[1] C. Ospelkaus *et al.*, Nature **476**, 181 (2011).
[2] C. Ospelkaus *et al.*, Phys. Rev. Lett. **101**, 090502 (2008).
[3] M. Carsjens *et al.*, Appl. Phys. B **114**, 243 (2014).
[4] M. Wahnschaffe *et al.*, Appl. Phys. Lett. **110**, 034103 (2017).

Q 40.4 Tue 16:15 Zelt West

Device-independent secret key rate from optimized Bell inequality violation — •Sarnava Datta, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätstraße 1, D-40225, Düsseldorf, Germany

Quantum Key distribution (QKD) is well established and starts entering in the commercial realm. However, due to divergence between theoretical models and practical devices, the security of such systems cannot be ensured. We consider the device-independent (DI) scenario, which avoids these problems. Our goal is to find an improved optimal Bell inequality violation using classical measurement data of a DIQKD protocol and to use this to find optimized bounds on the achievable DI secret key rate [1].

Reference

[1] L. Masanes, S. Pironio, and A. Acín , Nat. Commun. 2, 238 (2011).

Q 40.5 Tue 16:15 Zelt West

Technological Advances in Scalable Trapped Ion Quantum Computing — •Vidyut Kaushal, Janine Nicodemus, Daniël Pijn, Thomas Ruster, Björn Lekitsch, Ulrich Poschinger, and Ferdinand Schmidt-Kaler — Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Recent advances in trapped ion quantum technology have led to impressive results including the demonstration of four qubit GHZ states using subsequent entanglement gates [1] and a dc magnetometer with quantum enhanced sensitivity [2]. We will present the underlying technological advancements, starting with a high-speed multi-channel waveform generator developed in Mainz. The system delivers voltages and waveforms required for high-fidelity gate operations and fast ion transport, splitting and rearrangement of multiple ions. Voltage waveforms are computed using a custom developed software framework, which is capable of automatically generating ideal waveforms for various ion transport operations. In addition, we will discuss improvements of the quantizing magnetic field stability, which is critical for high qubit state coherence times. Electric coils were replaced using dual-type permanent magnets and the setup extended with a mu-metal chamber, leading to a significant improvement of coherence times [3].

[1] H. Kaufmann et al., Phys. Rev. Lett. 119, 150503 (2017)
[2] T. Ruster et al., Phys. Rev. A 90, 033410, 033410 (2014)
[3] T. Ruster et al., Appl. Phys. B 122:254 (2016)

Q 40.6 Tue 16:15 Zelt West

Simultaneous single ion addressing for quantum information processing — •Julian Rickert, Alexander Erhard, Roman Stricker, Lukas Postler, Esteban Martinez, Thomas Monz, Philipp Schindler, and Rainer Blatt — Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

Single ion addressing is a major challenge for building a trapped ion quantum computer. We propose a novel single ion addressing scheme which allows simultaneous manipulation of multiple ions. This newly developed scheme will enable us to perform arbitrary operations on each ion in the trap simultaneously. This will enable the generation of entanglement between ions in an arbitrary subset of all ions in one trap. The addressing scheme is implemented via an array of fibers where each fiber is imaged onto a single ion. Adjustment to the ion spacing is performed with a micro mirror array, where each fiber output beam hits a single mirror of the array. A telescope between mirror array and objective forms the laser beam such that we can get spot sizes of around one micrometer, smaller than the inter-ion distance. Timing control is obtained by a separate fiber AOM for each fiber output, providing full phase, intensity and frequency control.

Q 40.7 Tue 16:15 Zelt West

Scalable quantum computation - Keeping a qubit alive — •Lukas Gerster[1], Martin van Mourik[1], Matthias Brandl[1], Lukas Postler[1], Thomas Monz[1], Philipp Schindler[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften , Austria

Trapped ions are a promising platform to host a future quantum computer.

In our setup we use a planar segmented trapping architecture in a cryostat to demonstrate scalable quantum manipulation. The setup has been designed to reduce magnetic field noise and mechanical vibrations which both can induce errors. [1] Two species, $^{40}Ca^{+}$ and $^{88}Sr^{+}$, are co-trapped, allowing for recooling of ion crystals during sequences. We have modified the setup to host a high optical access trap [2], featuring in vaccum-optics with high collection efficiency for high fidelity state readout.

We further present ion crystal rotation of both single and multi species ion crystals with only few phonons accumulated per rotation, similar to [3]. These operations expand the available toolbox, enabling quantum error correction protocols in the future.

[1] M. Brandl et al, *Cryogenic setup for trapped ion quantum computing*, 10.1063/1.4966970
[2] P. Maunz, *High Optical Access Trap 2.0*, 10.2172/1237003
[3] H. Kaufmann et al, *Fast ion swapping for quantum-information processing*, 10.1103/PhysRevA.95.052319

Q 40.8 Tue 16:15 Zelt West

Microfabricated linear ion trap arrays for quantum simulation — •Gerald Stocker[1,2], Philip Holz[1], Kirill Lakhmanskiy[1], Yves Colombe[1], Rainer Blatt[1,3], Clemens Rössler[2], and Sokratis Sgouridis[2] — [1]Institut für Experimentalphysik, Uni Innsbruck, Österreich — [2]Infineon Technologies Austria AG, Villach, Österreich — [3]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria

Linear chains of trapped ions are used for quantum simulation of 1D spin systems [1]. 2D arrays of ion traps may allow to extend the range of accessible simulations to systems with more than one spatial dimension. Here we report on the design and fabrication of linear ion traps that are arranged in a two-dimensional lattice on a microchip. The linear traps are segmented to create multiwells along the trap axes. An interaction zone allows to reduce the distance between adjacent wells along the axis to about $40\,\mu$m using DC control fields. In this way, coherent operations mediated by the Coulomb interaction should become possible [2]. Similarly, the distance between adjacent multiwells can be reduced in the direction perpendicular to the trap axes by tuning the RF voltage [3]. Additionally, the multiwells can be moved independently of each other along the trap axes. This scheme should enable digital simulation of spin systems with next-neighbor interactions on a square lattice as well as triangular lattices. [1] C. Monroe et al., Proceedings of the International School of Physics 'Enrico Fermi', Course 189, pp. 169-187 (2015) [2] A.C. Wilson et al., Nature 512, 57-60 (2014) [3] M. Kumph et al., New J. Phys. 18, 023047 (2016)

Q 40.9 Tue 16:15 Zelt West

Security of multipartite QKD protocols with finite resources — •Federico Grasselli, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität, Düsseldorf, Deutschland

We analyze the security of multipartite quantum key distribution protocols implemented with genuine multipartite entangled states as resources [1]. In particular, we focus on finite-size effects.
For this purpose, we consider the generalizations of the notions of security, correctness, secrecy and leakage of a protocol in the multipartite scenario. We then extend the upper bounds to the key length and to the leakage of an optimal error correction scheme -known for bipartite protocols- to the multipartite case.
Furthermore, we present a computable secret key rate for finite resources in the presence of coherent attacks, extending similar results already obtained in the bipartite case [2].

[1]: M. Epping, H. Kampermann, C. Macchiavello, D. Bruß. New J. Phys. 19 093012, 2017.

[2]: M. Mertz, H. Kampermann, S. Bratzik, D. Bruß. Phys. Rev. A 87 012315, 2013.

Q 40.10 Tue 16:15 Zelt West

Prevention of Side-Channel Attacks in Timebin-Entanglement Based QKD Protocols — •Alexander Sauer and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt

Bell tests are a crucial part of many key distribution protocols in quantum cryptography. To prevent side-channel attacks, it is necessary to close all loopholes in these tests, which might be exploited by an adversary. We investigate schemes based on timebin-entanglement with respect to their vulnerability to the fair-sampling loophole and the impact of detector inefficiencies. We propose a modified experimental setup to overcome the arising limitations of Franson-type interferometers [1].

[1] J. D. Franson, Phys. Rev. Lett. 62, 2205 (1989)

Q 40.11 Tue 16:15 Zelt West

Overview over recent quantum key distribution activities at MPL — Ömer Bayraktar[1,2], Dominique Elser[1,2], Tobias Frank[1,2], •Kevin Günthner[1,2], Kevin Jaksch[1,2], Imran Khan[1,2], Christian R. Müller[1,2], Jonas Pudelko[1,2], Stefan Richter[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [2]IOIP, Friedrich-Alexander University Erlangen-Nuremberg (FAU), Staudtstr. 7/B2, 91058 Erlangen, Germany

Quantum key distribution (QKD) can provide secure communication, even in the upcoming era of quantum computers. Thus, QKD is one of the most highlighted and developed quantum technologies. Over the last years, this research area has been investigated intensively at the Max Planck Institute for the Science of Light (MPL) in Erlangen. On this poster, we give an overview of these activities. We study both fiber-based QKD, being compatible with existing telecom technology [1], as well as free-space channels. Here, we analyze urban scenarios using our free-space link in Erlangen [2] as well as long-haul satellite quantum communication [3]. Additionally, we present our plans for the spin-off InfiniQuant, aiming towards commercialization of our QKD systems.

[1] I. Khan et al., QCrypt 2016
[2] B. Heim et al., New J. Phys. **16**, 113018 (2014)
[3] K. Günthner et al., Optica **4**, 611-616 (2017)

Q 40.12 Tue 16:15 Zelt West

Quantum key distribution with small satellites — Peter Freiwang[2] and •QUBE Konsortium[1,2,3,4,5] — [1]Deutsches Zentrum für Luft- und Raumfahrt IKN, Oberpfaffenhofen — [2]Ludwig-Maximilians-Universität, München — [3]Max-Planck-Institut für die Physik des Lichts, Erlangen — [4]OHB System AG, Oberfaffenhofen — [5]Zentrum für Telematik, Würzburg

Quantum Key Distribution (QKD) over long distances becomes possible using optical links between satellites and ground stations on earth. Connecting to different ground stations one after the other enables secure key exchange on a global scale. Here we present a concept for a simple and compact nano-satellite QKD-payload allowing for the generation of BB84 polarization encoded faint laser pulses. A new level of integration was achieved by using micro optical components and a waveguide circuit resulting in a robust and stable optical unit with the size of a match. The micro optical packaging and the control electronics are combined on a 9 x 9 cm* printed circuit board. We describe the concept of the nano-satellite, a so called cube-satellite as small as 10 x 10 x 30 cm3. Because of their size and weight, cube-satellites represents an economical platform for testing of technologies in space in general. Thanks to the low costs, they have the potential to form flotillas to become the backbone for a global QKD network.

Q 40.13 Tue 16:15 Zelt West

Towards Single Neutral Atoms in Crossed Fiber Cavities — •Joseph Dale Christesen, Dominik Niemietz, Manuel Brekenfeld, Manuel Uphoff, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Cavity quantum electrodynamics provides a rich toolbox for the investigation of fundamental phenomena in quantum physics through increased light-matter coupling which enables many intriguing applications in quantum information processing. One method to further increase the light-matter coupling for a neutral atom trapped in a cavity is to decrease the cavity mode volume. Limits on the reduction of the cavity mode volume imposed by traditional manufacturing processes of the cavity mirrors have been overcome with the introduction of fiber cavities [1], where fiber end facets are machined by means of CO_2 laser ablation. Besides small mode volumes and larger coupling rates, fiber cavities also allow for new cavity geometries due to their smaller dimensions, including coupling a single emitter to two independent and perpendicular cavity modes. We are currently setting up a new experiment consisting of two crossed fiber cavities which realizes this unique cavity geometry and also constitutes an important step towards the implementation of an integrated quantum repeater [2]. We will present the current status and future plans for our apparatus including fabrication results of elliptical and spherical fiber mirrors.

[1] Hunger *et al.*, NJP **12**, 065038 (2015)
[2] Uphoff *et al.*, Appl. Phys. B **122**, 46 (2016)

Q 40.14 Tue 16:15 Zelt West

Sagnac-type setup for the generation of tunable polarizationentangled photon pairs — •Golnoush Shafiee[1,2], Gerhard Schunk[1,2], Florian Sedlmeir[1,2], Alexander Otterpohl[1,2], Ulrich Vogl[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nürnberg, Erlangen, Germany — [3]The Dodd-Walls Centre for Photonic and Quantum Technologies, Department of Physics, University of Otago, Dunedin, New Zealand

Single photons and photon pairs are an important resource for quantum information processing. Our compact source of photon pairs [1] and squeezed light [2] is based on spontaneous parametric down conversion (SPDC) in a triply resonant whispering-gallery resonator (WGR) made of lithium niobate. Single-mode operation of this source has been demonstrated. The central wavelength of the emitted light can be tuned over hundreds of nanometer [3]. Currently, we investigate PDC in counter-propagating modes of one WGR. Here we study interference of the counter-propagating signals above and below the oscillation threshold. This system opens up novel possibilities for the creation of polarization-entangled photon pairs for proposed quantum repeater schemes.

[1] M. Förtsch et al., Nat. Commun. 4, 1818 (2013). [2] J. U. Fürst et al., Phys. Rev. Lett. 106, 113901(2011). [3] G. Schunk et al., Optica 2, 773-778 (2015).

Q 40.15 Tue 16:15 Zelt West

Towards a long lived multi-mode memory for photonic qubits — •Stefan Langenfeld, Matthias Koerber, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Quantum memories can preserve qubits for an extended duration. In combination with the capability to map photonic qubits into and out of the memory, this has important applications in quantum computation and communication. For instance, quantum repeater protocols rely on long storage times and the ability to access multiple qubits independently. After recently demonstrating a qubit memory featuring a coherence time compatible with global scale communication [1], we now are interested in implementing multi-qubit storage capabilities in the same system. This would promote single neutral atoms to a truly scalable architecture. Our system consists of several ^{87}Rb atoms trapped in a two-dimensional optical lattice in a high-finesse optical resonator. We use an imaging system capable of resolving single atoms [2]. In combination with an acousto-optic deflector this allows us to select an atom and steer an optical beam onto it independent of its non-deterministic position in the optical lattice. We will discuss our progress on the optical addressing and show first results demonstrating multi-qubit storage capabilities.

[1] M. Körber, O. Morin, S. Langenfeld et al., accepted for publication in Nat. Photonics
[2] A. Neuzner et al., Nat. Photonics 10, 303-306 (2016)

Q 40.16 Tue 16:15 Zelt West

Coupling individual Erbium ions to single telecom photons — •Lorenz Weiss, Natalie Wilson, Benjamin Merkel, and Andreas Reiserer — Max Planck Institute of Quantum Optics, Garching, Germany

Erbium ions in suited host crystals are promising candidates for large-scale quantum networks since they combine second-long ground state spin coherence times with coherent optical transitions at telecommunication wavelengths. Unfortunately, the extremely long lifetime of the excited state (14 ms) makes it difficult to spectrally resolve and control individual ions in order to harness them for quantum networks. To overcome this challenge, we employ Fabry-Perot cavities that contain micrometer-thin, erbium-doped yttrium orthosilicate (Y_2SiO_5) crystals. In initial experiments, we have observed a cavity finesse of 36 000. To achieve both a smaller mode volume and a higher resonator quality factor, we have then optimized both the sample surface roughness (below 0.2 nm rms) and the resonator size (to a few cubic wavelengths) by fabricating low-roughness depressions of small radius of curvature in fused silica. At cryogenic temperature, we thus expect to shorten the radiative lifetime of the optical transitions by three orders of magnitude via the Purcell effect. This will enable deterministic interactions between individual spins and single telecom photons, opening unique prospects for the realization of entanglement between spins over distances exceeding 100 km.

Q 40.17 Tue 16:15 Zelt West

Coupling of quantum emitters in Si_3N_4 photonic crystal nanobeam cavities — •Jan Olthaus[1], Doris E. Reiter[1], Philip Schrinner[2], and Carsten Schuck[2] — [1]Institut für Festkörpertheorie, Universität Münster, 48149 Münster, Germany — [2]Physikalisches Institut, Universität Münster, 48149 Münster, Germany

The efficient integration of single-quantum emitters with photonic circuits is a major challenge for the development of quantum technologies. A scalable implementation of single-photon emitters on a chip requires a low-loss interface and strong light-matter interactions. Here, we present results for geometry optimisations based on 3D-FDTD simulations of photonic crystal nanobeam cavities embedded with a Si_3N_4 waveguide. Our goal is to optimise the structure in terms of a low, wavelength-scale mode volume in combination with a high Q-factor of the localised cavity mode. Based on this geometry we analyze the coupling strength between the single-photon emitter and the dielectric waveguide dependent on the position and polarization of the source. Our results pave the way for an efficient integration of single-photon sources into photonic circuits.

Q 40.18 Tue 16:15 Zelt West

Towards cavity-enhanced detection of single rare earth ions — •Julia Benedikter[1,2], Bernardo Casabone[3], Thomas Hümmer[1], Alban Ferrier[4], Philippe Goldner[4], Theodor W. Hänsch[1,5], and David Hunger[2] — [1]Ludwig-Maximilians-Universität München, Germany — [2]Karlsruher-Institut für Technologie, Germany — [3]Institut de Ciències Fotòniques, Barcelona, Spain — [4]Chimie ParisTech, ENS, Paris, France — [5]Max-Planck-Institut für Quantenoptik, Garching, Germany

Rare earth ions doped into solids provide outstanding optical and spin coherence properties, which renders them as promising candidates for optically adressable quantum memories and multi-qubit registers. However, due to the dipole-forbidden nature of the coherent transitions, they couple only weakly to optical fields. This limits most experiments to macroscopic ensembles, where inhomogeneous broadening complicates and limits quantum control.

Here we present an approach to get efficient access to individual ions or small ensembles by coupling them to a high-finesse optical microcavity. We employ fiber-based Fabry-Perot cavities with high finesse and a free-space mode volume as small as a few λ^3 to achieve substantial Purcell enhancement. This offers the potential to boost the spontaneous emission rate by several orders of magnitude (up to 104), thereby making the weak transitions bright.

We report on the current status of our experiment, where we investigate Eu^{3+} : Y_2O_3 nanocrystals coupled to a cavity in a cryogenic environment.

Q 40.19 Tue 16:15 Zelt West

Nano-photonic circuits with integrated quantum emitter — •Philip Schrinner, Marius Otte, Rene Henke, and Carsten Schuck — Physikalisches Institut and Center for Nanotechnology, WWU Münster, Germany

Realizing quantum information processing technologies on a scalable platform are expected to have a disruptive impact on cryptography, communication and computing. Advanced CMOS fabrication is a promising tool for integrating large-scale quantum photonic circuits on silicon. We consider such a system, where single photons are manipulated in nano-photonic waveguide devices. The implementation consists of single photon sources (SPS), nano-photonic circuits and single photon detectors. In this work we aim on coupling nano-scale quantum emitters with waveguide devices to supply single-photons into photonic integrated circuits. We present techniques to deterministically place the nano emitters in the evanescent field of an optical waveguide, where nitrogen vacancy centers in nano diamonds serve as an example. Additionally, suitable nano-photonic devices for the integration of nano emitters are rapidly prototyped by employing nanofabrication routines and automated fiber-optic measurement capabilities. The spectral and statistical properties of quantum emitters are at first investigated in confocal microscopy. After the positioning process the coupling between the quantum emitter and an optical waveguide is investigated. Integration of single-photon sources with SNSPDs linked via nanophotonic circuits on a silicon chip will then constitute a key step towards scalable quantum information processing.

Q 40.20 Tue 16:15 Zelt West

Resonant excitation of defect centers in hexagonal Boron Nitride (hBN) — •Markus Bürk[1], Andreas Dietrich[1], Igor Ahoronovich[2], Kerem Bray[2], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Insitute for Quantum Optics, Ulm University, D-89081 Ulm — [2]School of Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, NSW, 2007, Australia

Recent experiments demonstrated resonant excitation of single defect centers in 2D-material hexagonal Boron Nitride [1]. We present our recent results on resonant excitation of different defect centers in hBN in absence of spectral diffusion or dephasing for as long as 30 s at cryogenic temperatures (4 K). Our investigations include resonant photoluminescence excitation (PLE) of single photon emitters in a wide optical range. Furthermore, we investigated the polarization properties and phonon side band features of the defects. Together with a long coherence time [2] these properties make hexagonal Boron Nitride a promising candidate for quantum optical applications like quantum repeaters.

[1] Tran, Toan Trong, et al. "Resonant excitation of quantum emitters in hexagonal boron nitride." ACS Photonics (2017).
[2]Abdi, Mehdi, et al. "Spin-mechanics with color centers in hexagonal boron nitride membranes." arXiv preprint arXiv:1704.00638 (2017).

Q 40.21 Tue 16:15 Zelt West

Surface treatment of hBN towards stable spectral lines — •Michael Koch, Andreas Dietrich, Richard Waltrich, Lukas Hartung, Stefan Häussler, Fedor Jelezko, and Alexander Kubanek — Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany

Due to its promising spectral properties [1, 2], hBN is a bright candidate for quantum optical applications like quantum repeaters. Spectral stability is a crucial property for single photon emitters and therefore spectral diffusion is a limiting factor especially for hBN. We present techniques to improve the spectral properties of defect centers in hBN by different surface treatment and annealing methods. We gain in-depth insight into the underlying physical processes leading to spectral instability.

[1] Tran, Toan Trong, et al. "Quantum emission from hexagonal boron nitride monolayers." Nature nanotechnology 11.1 (2016):37-41.

[2] Tran, Toan Trong, et al. "Resonant excitation of quantum emitters in hexagonal born nitride." ACS Photonics (2017).

Q 40.22 Tue 16:15 Zelt West

A close look on second order correlation measurements of quantum emitters in hexagonal boron nitride and their implications for the underlying level system — •Bernd Sontheimer[1], Merle Braun[1], Mehran Kianinia[2], Igor Aharonovich[2], and Oliver Benson[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin, — [2]School of Mathematical and Physical Sciences, University of Technology Sydney

Single photon sources (SPSs) are prime candidates for a myriad of applications in integrated quantum optics and information processing. Quantum emitters in hexagonal boron nitride (hBN), a wide-band-gap two-dimensional material, have recently emerged as promising SPSs. While the origin and atomic structure of these emitters are still under debate, they can exhibit remarkable properties including the ability of sub-band-gap excitation at room temperature, high brightness and short excited state lifetime. Here, we present our latest insights on the underlying level system and rate models gained from second-order correlation measurements of single photon streams emitted by isolated defects. By performing measurements at different excitation laser powers, we can carefully match the resulting graphs to theoretical predictions for different models and extract transition rates as well as saturation behaviors of the participating electronic states. We find at least one exceptionally long-lived metastable state and repumping mechanisms that can be exploited in super-resolution microscopy schemes.[1] Furthermore, our results experimentally complement density functional theory modeling of the emitters atomic structure. [1]arXiv:1709.08683

Q 40.23 Tue 16:15 Zelt West

Single Praseodymium Ions in the Solid State: Towards a Long-Lived Quantum Memory — •André Pscherer[1,2], Emanuel Eichhammer[1], Tobias Utikal[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), D-91058 Erlangen

Rare earth ions embedded in solid state crystals are very attractive for quantum information processing due to their exceptionally long spin coherence time which can reach up to six hours [1]. Despite long fluorescence lifetimes, in the past years several groups have demonstrated the optical detection of single rare-earth ions at cryogenic temperatures by spatial or spectral selection [2]. However high resolution spectroscopy has revealed spectral diffusion as the main obstruction for quantum information processing at the single ion level. Here we report on our recent efforts to minimize spectral diffusion by reducing the crystal defect density and the temperature to superfluid helium.

[1] M. Zhong, *et al.* Nature 517 (2015): 177 – 180.

[2] T. Utikal, *et al.* Nature Communications 5 (2014): 3627.

Q 40.24 Tue 16:15 Zelt West

Localized Modes in leaky dielectric nanoresonators: a general optimization strategy for photon extraction — •Niko Nikolay[1], Günter Kewes[1], Felix Binkowski[2], Lin Zschiedrich[2], Sven Burger[2], and Oliver Benson[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Zuse Institute Berlin

When considering solid state emitters and their emitted photons to act as qubits and flying qubits in a quantum network, it is crucial to efficiently link both. A technical realization of this link is an antenna. Current design concepts often suffer from a large footprint, quenching or a complex fabrication process [1-3]. Here we show another very general design concept where the Kerker effect [4] is used to redirect and collimate emission from single emitters, exemplary discussed on a nitrogen vacancy (NV) center. The antenna is an easy to fabricate cylindrical protrusion (a nanodisk with small aspect ratio) made from a medium of moderate or high refractive index (e.g., diamond, ZnO, SiN or GaAs) etched into a substrate of the same material. Such a simple structure supports leaky localized modes that lead to directed emission by de- and constructive interference. To analyze the antenna we employ a versatile optimized quasi normal mode method that gives a clear view on the otherwise obscured underlying physics of this antenna type. Emitters may be incorporated inside the antenna or placed on top.

[1] P. Muehlschlegel, science 308.5728, 1607-1609 (2005)

[2] K. G. Lee, Nature Photonics 5.3, 166-169 (2011)

[3] M. Gschrey, Nature communications 6 (2015)

[4] M. Kerker, JOSA 73.6, 765-767 (1983)

Q 41: Ultracold Plasmas and Rydberg systems III (joint session A/Q)

Time: Wednesday 14:00–15:45 Location: K 0.011

Q 41.1 Wed 14:00 K 0.011

Van der Waals interaction potential between Rydberg atoms near surfaces — •Johannes Block and Stefan Scheel — Institut für Physik, Universität Rostock, D-18059 Rostock, Germany

Rydberg atoms experience strong van der Waals interactions due to their large transition dipole moments. As these interactions are mediated by photons, they can be altered by dielectric surroundings. As a model system for atoms near a superconducting stripline cavity, we show the effect of a mirror on the van der Waals interaction of Rydberg atoms by direct diagonalization of the interaction Hamiltonian including terms up to electric quadrupole-quadrupole interaction [1,2]. We find that the presence of the mirror strongly modifies the interactions leading to a significant change in the Rydberg blockade [3].

[1] J.S. Cabral *et al.*, J. Phys. B: At. Mol. Opt. Phys. **44**, 184007 (2011).

[2] J. Stanovevic *et al.*, Phys. Rev. A **78**, 082709 (2008).

[3] J. Block and S. Scheel, arXiv:1710.08965

Q 41.2 Wed 14:15 K 0.011

An optogalvanic flux sensor for trace gases — •Johannes Schmidt[1,2,5], Markus Fiedler[1,5], Ralf Albrecht[1,5], Denis Djekic[3,5], Patrick Schalberger[2,5], Holger Baur[2,5], Robert Löw[1,5], Tilman Pfau[1,5], Jens Anders[3,5], Norbert Frühauf[2,5], Edward Grant[4], and Harald Kübler[1,5] — [1]5th Institute of Physics — [2]Institute for Large Area Microelectronics — [3]Institute for Theory of Electrical Engineering — [4]Department of Chemistry, University of British Columbia — [5]University of Stuttgart, Center for Integrated Quantum Science and Technology (IQST)

We demonstrate the applicability of a new kind of gas sensor based on Rydberg excitations. From an arbitrary probe gas the molecule in question is excited to a Rydberg state, by succeeding collisions with all other gas components this molecule gets ionized and the emerging electron and ion can then be measured as a current, which is the clear signature of the presence of this particular molecule. As a first test we excite Alkali Rydberg atoms in an electrically contacted vapor cell [1,2] and demonstrate sensitivities down to 100 ppb on a background of N_2. We investigate different amplification circuits, ranging from solid state devices on the cell to thin film technology based transimpedance amplifiers inside the cell [3]. For a real life application, we employ our gas sensing scheme to the detection of nitric oxide in a background gas at thermal temperatures and atmospheric pressure.

[1] D. Barredo, et al., *Phys. Rev. Lett.* **110**, 123002 (2013)

[2] R. Daschner, et al., *Opt. Lett.* **37**, 2271 (2012)
[3] J. Schmidt, et al., *AMFPD* **24**, 296-298 (2017)

Q 41.3 Wed 14:30 K 0.011

Rydberg molecules for ion-atom scattering in the ultracold regime — •Thomas Schmid[1], Christian Veit[1], Nicolas Zuber[1], Thomas Dieterle[1], Christian Tomschitz[1], Robert Löw[1], Michal Tarana[2], Michal Tomza[3], and Tilman Pfau[1] — [1]5. Physikalisches Institut & Center for Integrated Quantum Science and Technology, Universität Stuttgart, Germany — [2]J. Heyrovskzý Institute of Physical Chemistry of the ASCR, Prague, Czech Republic — [3]Centre of New Technologies & Faculty of Physics, University of Warsaw, Poland

We propose a novel experimental method to extend the investigation of ion-atom collisions from the so far studied cold regime to the unexplored ultracold regime [1]. Key aspect of this method is the use of Rydberg molecules to initialize the ultracold ion-atom scattering event. We exemplify the proposed method with the lithium ion-atom system, for which we present simulations of how the initial Rydberg molecule wavefunction, freed by photoionization, evolves in the presence of the ion-atom scattering potential. We predict bounds for the ion-atom scattering length from *ab initio* calculations of the interaction potential. We demonstrate how the scattering length can be experimentally determined from the scattered wavepacket. Finally, we present our ultracold Rb-Li Rydberg setup containing an ion microscope and a delay-line detector to allow for the temporally and spatially resolved detection of the scattered ion-atom wavepacket.

[1] T. Schmid et al.; *arXiv* 1709.10488 (2017).

Q 41.4 Wed 14:45 K 0.011

Epidemic dynamics in open quantum spin systems — Carlos Perez-Espigares[1], •Matteo Marcuzzi[1], Ricardo Gutierrez[1,2], and Igor Lesanovsky[1] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [2]Complex Systems Group, Universidad Rey Juan Carlos, 28933 Móstoles, Madrid, Spain

We derive a simple epidemic spreading process to describe the nonequilibrium dynamics of an open many-body system, motivated by recent experiments realised with strongly-interacting gases of highly-excited (Rydberg) atoms, in which the facilitated excitation of Rydberg states competes with radiative decay in a three-level structure. This is approximately mapped onto a population dynamics model where individuals can be either healthy, infected or immunised, and which displays a continuous phase transition from a regime where the epidemic stops to one where instead it can continue spreading indefinitely. The study of the strongly-dephased (classical) regime displays signatures of this continuous phase transition, whereas a preliminary analysis of the weakly-dephased (quantum) regime suggests a shift to a sequence of discontinuous jumps. We discuss the limitations of our modelling imposed by a more realistic setting of laser-driven Rydberg atoms, with a particular focus on the role of the long-range tails of the interactions.

Q 41.5 Wed 15:00 K 0.011

Multi-excitons in flexible Rydberg aggregates — •Ghassan Abumwis[1,2] and Sebastian Wüster[1,2,3] — [1]mpipks, Dresden, Germany — [2]Bilkent University, Ankara, Turkey — [3]IISER, Bhopal, India

Flexible Rydberg aggregates are ensembles of Rydberg atoms that are allowed to move, they provide a platform to investigate quantum phenomena like energy transport and conical intersections. This can be achieved by doping the aggregate with an excitation, an excited state that is energetically higher but close to the primary Rydberg state, leading to the resonant dipole-dipole interaction becoming dominant. Consequently, the excitation is delocalized throughout the aggregate creating excitons.

We follow up on previous results and add a second excitation to the aggregate. We demonstrate that products of excitons can be used to express biexciton states for a chain with a dislocation at one end, a one-dimensional aggregate with equal spacing between atoms except for the last two. Moreover, we show that non-adiabatic effects can be made prominent in flexible Rydberg chains. Finally, we analyze the interaction between two excitation pulses based on the initial biexciton state and the presence of a dislocation. Our findings further enlarge the pool of Born-Oppenheimer surfaces for quantum transport that can be engineered in flexible Rydberg aggregates.

Q 41.6 Wed 15:15 K 0.011

Experimental realization of an Optical Feshbach resonance using ultra-long range Rydberg molecules — •Oliver Thomas[1,2], Carsten Lippe[1], Tanita Eichert[1], and Herwig Ott[1] — [1]Department of Physics and research center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

Over the last decades Feshbach resonances in ultra cold atomic gases have lead to some of the most important advances in atomic physics. Not only did they enable ground breaking work in the BEC-BCS crossover regime, but they are also a widely used tool for the association of ultra cold molecules. Leading to the observation of the first molecular Bose-Einstein Condensates and the emergence of ultra cold dipolar molecular systems. We show the experimental realization of optical Feshbach resonances using ultra-long range Rydberg molecules and demonstrate their practical use by tuning the revival time of a quantum many-body system quenched into a deep optical lattice. We believe this opens up a complete new field of Feshbach resonances as ultra-long range Rydberg molecules have a plenitude of available resonances for nearly all atomic species.

Q 41.7 Wed 15:30 K 0.011

Pendular states of butterfly Rydberg molecules — •Carsten Lippe[1], Oliver Thomas[1,2], Tanita Eichert[1], and Herwig Ott[1] — [1]Department of Physics and research center OPTIMAS, University of Kaiserslautern — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz

Butterfly Rydberg molecules are a special class of Rydberg molecular states arising from a shape resonance in the p-wave scattering channel of a ground state atom and a Rydberg electron. They owe their name to the shape of the electronic wavefunction which resembles the shape of a butterfly.

We have performed high resolution photoassociation spectroscopy of uv-excited deeply bound butterfly Rydberg molecules of ^{87}Rb. We find states bound up to -50GHz from the $25\mathrm{P}_{1/2}, F = 1$ and $25\mathrm{P}_{1/2}, F = 2$ state, corresponding to bond lengths of $50\,a_0$ to $500\,a_0$.

Due to strong admixture of high angular momentum states the butterfly Rydberg molecules feature giant permanent electric dipole moments of hundreds of Debye which allow us to resolve the rotational structure of the Rydberg molecules and observe pendular states. This enables an unprecedented degree of control over the orientation of dipolar molecules even in weak electric fields.

Furthermore, the identification of different structures of pendular state spectra which can be attributed to different total angular momentum projections helps to map the detected molecular bound states to the corresponding potential energy curves.

Q 42: Quantum Optics and Photonics II

Time: Wednesday 14:00–16:00 Location: K 0.016

Group Report Q 42.1 Wed 14:00 K 0.016

The Accelerator on a Chip International Program: Status and Outlook — •Joshua McNeur[1], Norbert Schönenberger[1], Ang Li[1], Peyman Yousefi[1], Johannes Illmer[1], Peter Hommelhoff[1], and The ACHIP Team[2,3,4,5,6,7] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstr. 191058 Erlangen, Germany — [2]Stanford University, Stanford, USA — [3]SLAC National Accelerator, Stanford, USA — [4]University of California - Los Angeles, Los Angeles, USA — [5]Uni Darmstadt, Darmstadt, Germany — [6]Paul Scherrer Institut, Villigen, Switzerland — [7]Deutsches Elektronen-Synchrotron, Hamburg, Germany

Dielectric laser acceleration (DLA) is based on the interaction of electrons and laser-excited near-fields at photonic structures. The resulting demonstrated acceleration gradients approaching 1 GeV/m over varying wavelengths and electron energies make this technology promising as a candidate for a small-footprint accelerator. The Accelerator on a Chip International Program (ACHIP) has been researching

DLA in order to realize many of its exciting applications. Specifically, it aims to design and demonstrate a MeV electron accelerator with a shoebox-sized footprint. Here the status and outlook of this endeavor are summarized. Specifically, challenges and developments related to the necessary high brightness cathodes, transverse and longitudinal subrelativistic electron dynamics, on-chip photonics-based laser coupling and the integration of all components of the envisioned MeV accelerator are detailed. This work is supported by the Gordon and Betty Moore Foundation.

Q 42.2 Wed 14:30 K 0.016

Driving Transitions between States in Topological Systems — •Christina Jörg[1], Fabian Letscher[1,2], Christoph Dauer[1], Axel Pelster[1], Sebastian Eggert[1], Michael Fleischhauer[1], and Georg von Freymann[1,3] — [1]Physics Department and Research Center OPTIMAS, TU Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Kaiserslautern, Germany — [3]Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany

On the one hand, edge states in topologically ordered systems have shown to be robust against many local perturbations [1-4]. On the other hand, it is known that periodic driving can induce transitions between different continuum states [5]. Here, we examine how to drive a transition between bulk states and an edge state in topologically nontrivial systems using a local AC-field. Our model system consists of evanescently coupled waveguides. They are positioned along x to form a Su-Schrieffer-Heeger (SSH) lattice with a defect that is periodically modulated in its position. We study how the time evolution of this system depends on the driving frequency and amplitude of the defect modulation. While for low frequencies the edge mode remains localized, we observe a strong coupling to bulk modes whenever the driving frequency is resonant with a bulk band in the SSH model.

[1] C. Jörg, et al., New J. Phys. **19**, 083003 (2017).
[2] S. Mittal, et al., PRL **113**, 087403 (2014).
[3] M. C. Rechtsman, et al., Nature **496**, 196 (2013).
[4] Z. Wang, et al., Nature **461**, 772 (2009).
[5] S. Reyes, et al., New J. Phys. **19**, 043029 (2017).

Q 42.3 Wed 14:45 K 0.016

Coupled Resonators for Topologically Stabilized Photonic Circuits — •Maik Stappers[1,2], Nico Gruhler[1,2,3], Robert Löw[4], Tilman Pfau[4], and Wolfram H. P. Pernice[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany — [2]CenTech - Center for Nanotechnology, Heisenbergstraße 11 48149 Münster, Germany — [3]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [4]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

Topological effects offer interesting applications in photonic circuits. Ring resonators can be coupled to one another in an 2D array in such a way that they exhibit optical edge states similar to the eletrical edge states in topological insulators. These edge states are protected from pertubations and could be utilized to build all-optical switches with a high integration density. In this scheme an optically excited thermal atomic vapor interacts with the evanescent light field inside the resonators and thus switches the path the light takes through the resonator array.

In this talk our progress towards integrated all-optical switches utilizing topological protection is presented.

Q 42.4 Wed 15:00 K 0.016

Characterization of ultra-high-Q Si_3N_4 micro-ring resonators with high-precision temperature control — •Paul Kaufmann[1], Xingchen Ji[2], Kevin Luke[2], Michal Lipson[2], and Sven Ramelow[1] — [1]Humboldt-Universität zu Berlin, Berlin, Deutschland — [2]Columbia-University, New York City, USA

On-chip integrated micro-resonators with vastly enhanced nonlinearities are increasingly relevant for application in quantum optics, e.g. as ultra-compact sources of entangled photon pairs. While commonly used in the telecom band, their application in the near-visible wavelength range of 800-900 nm is particularly interesting both for free space communication and to interface photons with optical transitions in alkali vapors used in quantum memories (i.e. Cs D2 at 852 nm). Here, we report the observation of ultra-high-Q resonances in high-confinement Si_3N_4 micro-ring resonators, reaching loaded Q-factors of 2×10^6 at 850 nm corresponding to linewidths of 150 MHz. In contrast to common laser-scanning techniques, we characterize these narrow resonances using robust and cost-effective mK-precision temperature tuning of the chip. This allows us to control and characterize the temperature shift of the resonances with an unprecedented precision of 4 MHz/K. We will discuss advantages and limitations of this method and describe potential applications for our ultra-high-Q resonator devices as bright and compact narrow-band photon pair sources.

Q 42.5 Wed 15:15 K 0.016

Integrated nonlinear silicon-nitride microresonators for multi-wavelength generation — •Helge Gehring[1,2], Nico Gruhler[1,2], and Wolfram H. P. Pernice[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany

The need for higher data rates in both, classical and quantum communication, is rapidly increasing in recent years. One approach for satisfying this demand is transmitting signals on multiple wavelengths. Instead of using multiple laser sources, integrated nonlinear microring resonators can be employed for generating narrow-band emission at several well-separated wavelengths from a single pump laser source. At sub-threshold pump powers even spectrally correlated single-photon pairs can be produced.

Here we present our steps towards integrated sources for multi-wavelength communication using nonlinear silicon-nitride ring resonators on silicon chips. We present a theoretical study of the group velocity dispersion, which is a crucial parameter for efficient wavelength conversion and the development of a fabrication process that enables four-wave-mixing in nanophotonic circuits.

Q 42.6 Wed 15:30 K 0.016

Non-Abelian Gauge Fields in Integrated Photonic Waveguide Structures — •Mark Kremer, Lucas Teuber, Alexander Szameit, and Stefan Scheel — Institut für Physik, Universität Rostock, D-18055 Rostock, Germany

Simulating quantum effects using platforms like ultra cold atoms, waveguides, and microwave resonators offers new insights into numerous intriguing physical effects such as particle interaction, disorder-induced localization, and topological insulation. In the past few years, the concept of quantum simulators was extended to the realm of non-Abelian physics in the framework of lattice gauge theory, in particular using the platform of ultra cold atoms [1].

In our work we demonstrate how non-Abelian gauge fields can be simulated in photonics, using integrated laser-written photonic waveguide structures. To this end, we utilize dark states of a STIRAP-like process, originally introduced for manipulating the population of different (atomic) states by geometric phases [2]. A well adjusted modulation of waveguides forming a four-site system induces a non-Abelian gauge field whose gauge-independent Wilson loop can be experimentally retrieved via intensity measurements at the end facet of the waveguide structure.

[1] Dalibard, J. et al., Rev. Mod. Phys. 83, 1523 (2011).
[2] Unanyan, R. G. et al., Phys. Rev. A, 2910 (1999).

Q 42.7 Wed 15:45 K 0.016

Calculating with light - an all-optical abacus using phase-change materials — •Johannes Feldmann[1], Matthias Stegmaier[1], Nico Gruhler[1], Carlos Rios[2], Harish Bhaskaran[2], David Wright[3], and Wolfram Pernice[1] — [1]Physikalisches Institut, WWU Münster, Germany — [2]Department of Materials, University of Oxford, United Kingdom — [3]Department of Engineering, University of Exeter, United Kingdom

Since conventional data processing based on the von Neumann architecture faces more and more difficulties in increasing the processing speeds due to limitations in electrical data transfer and heat dissipation, substantial research is dedicated to developing new and unconventional processing schemes as e.g. brain inspired computing using neural networks or accumulation based computing.

A recently emerging technology in this field is based on memristor devices that combine memory and resistor in one element and help to circumvent the need to shuffle data between processor and memory but instead calculate and store it in the same physical location. In our work we transfer these ideas to a nanophotonic platform using phase-change materials embedded on top of integrated waveguides to enable fast and low energy arithmetic in analogy to an abacus. Employing single picosecond optical pulses with energies below 20 pJ our on-chip devices are capable of addition, subtraction, multiplication and division directly in base ten in speeds approaching the GHz-range. Using a waveguide-crossing array we present a scalable nanophotonic framework providing first steps towards non-von Neumann computation.

Q 43: Nano-Optics (Single Quantum Emitters)

Time: Wednesday 14:00–16:15 Location: K 0.023

Group Report Q 43.1 Wed 14:00 K 0.023

Towards Energy Transfer-based Sensing and Imaging with Color Centers in Single-Crystal Diamond — •Richard Nelz, Michel Challier, Ettore Bernardi, and Elke Neu — Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken

Individual nitrogen vacancy (NV) color centers in diamond are bright, photo-stable dipole emitters [1]. Consequently, they represent optimal candidates for novel scanning near field microscopy techniques [2]. Here, NV centers form one member of a Förster Resonance Energy Transfer (FRET) pair. Due to their broadband emission (> 100 nm), NVs are versatile donors for FRET to systems absorbing in the near infrared spectral range. Promising applications include, e.g., nanoscale imaging of fluorescent molecules or nanomaterials like graphene [2].

Critical parameters for FRET are the NV's quantum efficiency, charge state stability and distance to the sample. Previous experiments used NVs in nanodiamond for FRET [2], however these NVs might suffer from quenching, instability and bad control of surface termination. We here adress this issue demonstrating quenching of NVs in single crystal diamond by applying graphene to the surface.

To bring NVs close (< 10 nm) to the sample, we establish optimized approaches in fabricating cylindrical nanostructures as scanning probes.

[1] Bernardi et al., Crystals **7** 124 (2017).
[2] Tisler et al., Nano Lett. **13** 3152-3156 (2013).

Q 43.2 Wed 14:30 K 0.023

Optimization of diamond nanopillars for nanoscale sensing applications — •Philipp Fuchs, Michel Challier, and Elke Neu — Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken

The negatively-charged nitrogen vacancy center (NV) in diamond has become a very promising candidate for the implementation of nanoscale quantum sensors. Especially its electronic spin system is highly-suitable for magnetic field sensing and can be read out using the NV's luminescence. To fully harness the NV's nanoscale sensing capabilities, we use cylindrical diamond structures, so-called nanopillars, on thin diamond membranes as atomic force microscopy probes. Placing an NV shallowly below the top facet of such a pillar enables sensing and imaging with nanoscale spatial resolution. To achieve maximum sensitivity, it is crucial to maximize the absolute number of collected NV luminescence photons. In this talk, we show results from comprehensive simulations aiming towards the optimization of the photonic properties of such pillars to reach this goal. Besides a detailed analysis of the influence of different geometric parameters, e. g. length, diameter and taper angle, we also show an optimized set of parameters which maximizes the collectible NV luminescence.

Q 43.3 Wed 14:45 K 0.023

Parabolic reflectors and nanostructures in bulk diamond for efficient single photon extraction and cavity coupling — •Tim Schröder[1,2], Noel H. Wan[1], Brendan J. Shields[3], Donggyu Kim[1], Sara Mouradian[1], Benjamin Lienhard[1], Michael Walsh[1], Hassaram Bakhru[4], and Dirk Englund[1] — [1]RLE, Massachusetts Institute of Technology, USA — [2]Niels Bohr Institute, University of Copenhagen, Denmark — [3]Department of Physics, University of Basel, Switzerland — [4]SUNY Polytechnic Institute, USA

We present micro- and nanofabrication schemes of photonic devices in bulk diamond. Via high-throughput grey-scale lithography parabolic reflectors are fabricated that allow for simulated broadband collection >75% of the emission of defect centres in diamond [1]. The parabolic diamond-air interface redirects the emission of a defect located at the focal point into a small numerical aperture, reaching a photon extraction efficiency of $(48 \pm 5)\%$. For a nitrogen-vacancy centre (NV) the overall detection efficiency is $(12 \pm 2)\%$, enabling single photon count rates of up to $(5.7 \pm 1.0) \times 10^6$ per second. For the fabrication of photonic crystal cavities from bulk diamond we apply an isotropic undercut process. This process enables instrument-limited optical quality factors exceeding 14 000 within 1 nm of the NV zero phonon line, as well as uniform nanocavity fabrication across a full chip [2].

[1] N. H. Wan, B. J. Shields, D. Kim, S. Mouradian, B. Lienhard, M. Walsh, H. Bakhru, T. Schröder, and D. Englund, arXiv:1711.01704 (2017). [2] S. Mouradian, N. H. Wan, T. Schröder, and D. Englund, Appl. Phys. Lett. 111, 021103 (2017).

Q 43.4 Wed 15:00 K 0.023

Efficient solid-state single-photon sources based on diamond colour centers coupled to plasmonic bullseye resonators — •Martin Zeitlmair[1], Florian Fertig[1], Philipp Altpeter[1], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Efficient single-photon sources are a key building block for many applications in quantum information science and ultra-sensitive phase, absorption, and fluorescence spectroscopy. Here, solid-state based sources employing defect centers in nanodiamonds are advantageous due to their emission of single photons even at room temperature. The isotropic emission behaviour, however, requires the efficient redirection of the emission by means of photonic or plasmonic nanostructures.

We couple single nitrogen-vacancy centers hosted in nanodiamonds to aluminium bullseye structures employing an AFM-based pick-and-place technique. The plasmonic resonator is realized by an electron-beam lithography based fabrication method on dielectric mirror substrates. By optimizing the design parameters of the nanoplasmonic device, strong redirection and self-focusing of light emitted by the defect center can be achieved over a broad spectral range.

Q 43.5 Wed 15:15 K 0.023

Fourier limited lines in hBN at cryogenic temperatures — •Andreas Dietrich[1], Markus Bürk[1], Elena Steiger[1], Igor Aharonovich[2], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]School of Mathematical and Physical Sciences, University of Technology Sydney,Ultimo, New South Wales 2007, Australia

Defect centers in layered hexagonal boron nitride (hBN) are among the most promising candidates as single photon sources in Quantum Optics applications [1]. Very recently resonant excitation of single defect centers in 2D-material hBN has been demonstrated [2], with linewidth $\sim$ 1 GHz being limited by rapid spectral diffusion. Here we present our recent results on resonant excitation on defects in hBN in absence of spectral diffusion or dephasing for as long as 30 s at cryogenic temperatures, enabling us to measure Fourier limited lines of 55 MHz $\pm$ 10 MHz. Additional we report single photon emitters in hBN over a wide optical range and investigate phonon side-band emission. Fourier limited lines in a wide optical range with potentialy long coherence times [3] make hBN a promising candidate for applications such as quantum repeaters.

[1] Tran, Toan Trong, et al. Nature nanotechnology 11.1 (2016): 37-41.
[2] Tran, Toan Trong, et al. ACS Photonics (2017).
[3] Abdi, Mehdi, et al. arXive preprint arXiv:1704.00638 (2017)

Q 43.6 Wed 15:30 K 0.023

Resonant excitation studies of single dichroic vacancy centres in silicon carbide — Roland Nagy[1], •Florian Kaiser[1], Matthias Niethammer[1], Matthias Widmann[1], Durga Dasari[1], Ilja Gerhardt[1], Öney Soykal[2], Nguyen Tien Son[3], Christian Bonato[4], Sang-Yun Lee[5], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Naval Research Laboratory, Washington, USA — [3]Department of Physics, Chemistry and Biology, Linköping University, Sweden — [4]IPAQS, SUPA, Edinburgh, UK — [5]CGI, KIST, Seoul, Korea

Solid-state color centres are promising systems for scalable quantum information architectures. The ideal system meets three key features:

first, millisecond electron spin coherence times to permit quantum state manipulation and coupling to other spins; second, a large fraction of photons must be emitted in the zero phonon line to generate spin-photon entanglement; third, excellent spectral stability.

We show that all three criteria are met by the dichroic vacancy defect center (V1) in 4H-SiC [1]. The V1 center is a S=3/2 spin system with well-separated optical transitions at 861 nm [2]. We perform resonant optical excitation studies on single V1 centers to explore the ground and excited state level structures. We study also the spin dynamics and note that no spectral diffusion has been observed. Therefore, our results pave the way for a robust and scalable quantum information platform based on color centers in silicon carbide.

[1] R. Nagy et al., arxiv:1707.02715 (2017)

[2] M. Widmann et al., Nat. Mater. 14, 164 (2015)

Q 43.7 Wed 15:45 K 0.023

Two-photoninterference in an atom- quantum dot hybrid system — •Hüseyin Vural[1], Simone L. Portalupi[1], Julian Maisch[1], Simon Kern[1], Jonas H. Weber[1], Markus Müller[1], Michael Jetter[1], Jörg Wrachtrup[2], Robert Löw[3], Ilja Gerhardt[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, IQST and SCoPE, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]3. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [3]5. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

Future quantum networks require flying qubits and stationary nodes. Hybridization of single semiconductor quantum dots (QD), which provide ultra-bright on-demand single-photon emission, and alkali vapors with their possibility of broadband photon storage capabilities constitute a reasonable platform for networks. However, spectral diffusion, inherent in most solid-state emitters, is a limiting aspect to the photonic quantum optical properties. Here, we investigate the role of spectral diffusion of QDs on the hybridization with a cesium (Cs)-vapor. Fine-tuning the QD emission between the Cs-D1 transitions enables a temperature dependent delay on the single quanta. The strong dependence of this effect on the photon's frequency is used to map spectral domain into temporal one, thus revealing insight into the diffusion dynamics. Moreover coherence of photon-vapor interaction is proved to be conserved by means of two-photon interference measurements. Theoretically achievable performances are presented.

Q 43.8 Wed 16:00 K 0.023

Exciton-exciton dynamics in para-xylylene bridged perylene bisimide macrocycles — •Ulrich Müller[1], Peter Spenst[2], Matthias Stolte[2], Frank Würthner[2], and Jens Pflaum[1,3] — [1]Experimentelle Physik VI, Julius-Maximilians-Universität, Würzburg — [2]Institut für Organische Chemie, Julius-Maximilians-Universität, Würzburg — [3]ZAE Bayern, Würzburg

Multi-chromophoric systems serve as strong links between free photons and excitonic excitations in nature and define promising compounds for non-classical light sources in quantum optics. In this context, we have identified Perylene Bisimides (PBIs) as a model system for strong absorption and efficient single photon emission at room temperature promoted by their chemical tunability and high photostability [1]. We compare para-xylylene bridged PBI-macrocycles to single chromophores by means of fluorescence correlation measurements. PBI-macrocycles act as bright single photon emitters since ultra-fast exciton-exciton-annihilation significantly suppresses the simultaneous emission of two photons. However, approaching single-excited state saturation by increasing the excitation intensity the co-existence of multi-excitonic states becomes more likely and controls the emission characteristics of the macrocycles while the emission of single chromophores remains largely unchanged. We consistently explain our observations by a stochastic Markov model and advance the understanding of excitation and relaxation processes in multi-chromophoric systems.

[1] F. Schlosser et al., *Chem. Sci.* **3**, 2778 (2012)

Q 44: Quantum Effects (Cavity QED)

Time: Wednesday 14:00–16:00 Location: K 1.013

Group Report Q 44.1 Wed 14:00 K 1.013

Collective atom–photon interactions in complex environments — •Stefan Yoshi Buhmann[1,2], Roberta Palacino[3], Saeideh Esfandiarpour[1], and Robert Bennett[1] — [1]University of Freiburg, Freiburg, Germany — [2]Freiburg Institute for Advanced Studies — [3]University of Palermo

We review how macroscopic quantum electrodynamics in linear media can be used to describe the quantised electromagnetic field in arbitrary geometries and its interaction with one or several identical atoms.

For two emitters coherently sharing an excitation in free space, one recovers the well known phenomenon of a superradiant enhancement or suppression of decay, depending on the initial state. We show that this behaviour can be manipulated by a nearby metal surface in a generalised Purcell effect [1].

An even stronger impact of environments can be found in a cavity environment. We find that the strong coupling of two atoms with a single cavity mode can lead to collective Rabi oscillations which sensitively depend on the atomic positions with respect to the mode profile [2].

[1] R. Palacino, R. Passante, L. Rizzuto, P. Barcellona, S. Y. Buhmann, J. Phys. B **50**, 154001 (2017).

[2] S. Esfandiarpour, R. Bennett, H. Safari, S. Y. Buhmann, `arXiv:1708.05586` (2017).

Q 44.2 Wed 14:30 K 1.013

Strong Purcell effect on a neutral atom coupled to a fiber cavity — •Eduardo Urunuela, Wolfgang Alt, Jose Gallego, Tobias Macha, Miguel Martinez-Dorantes, Deepak Pandey, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany

We observe sixfold Purcell broadening of an atomic resonance line of a ^{87}Rb atom, that is strongly coupled to a single-sided fiber-based Fabry–Pérot cavity. In our system, a single atom is trapped in a 3D optical lattice inside the cavity and externally driven by a near-resonant laser. The enhancement of the photon emission rate into the cavity mode corresponds to a cooperativity well beyond unity, with the resonator mode collecting up to 90% of the emitted photons. These photons build up an intra-cavity field that imprints a back-action on the atom's driving conditions, leading to an enhancement of more than an order of magnitude of the total atomic emission. The photon leakage through the transmissive mirror is the dominant factor of the cavity field decay ($\kappa \approx 2\pi \times 70\,\text{MHz}$), thus offering a high-bandwidth and fiber-coupled channel for single-photon interfacing. These properties are highly desirable in quantum network nodes such as fast and efficient quantum memories and single-photon sources.

Q 44.3 Wed 14:45 K 1.013

A Versatile Production Facility for Fiber-Based Mirrors — •Michael Kubista, Deepak Pandey, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

We report on a production facility for creating miniaturized fiber-based Fabry-Perot cavities, which have numerous applications in quantum information technology. A CO2 laser at 9.3 μm is used to produce mirror surfaces on fiber end facets using laser ablation [1], taking advantage of the higher absorption of silica glass at this wavelength [2]. Beam shaping and polarization control are employed to reduce mirror ellipticity. To reconstruct the profile of the mirror surfaces, a high-resolution inline Mirau interferometer has been built. Further steps will include the implementation of a multi-shot technique to create larger mirrors [3], and the use of GRIN-lenses to improve mode matching efficiency [4]. These versatile techniques will enable us to produce cavities for a wide range of applications such as quantum communication, surface analysis, and opto-mechanical devices.

[1] D. Hunger, T. Steinmetz, Y. Colombe, C. Deutsch, T. W. Hänsch, and J. Reichel, N. J. Phys. 12, 065038 (2010) [2] M. Uphoff, M. Brekenfeld, G. Rempe, S. Ritter, N. J. Phys. 17, 013053 (2015) [3] K. Ott, S. Garcia, R. Kohlhaas, K. Schüppert, P. Rosenbusch, R. Long, and J. Reichel, 9839-9853 (2016) [4] G. Gulati, H. Takahashi, N. Podoliak, P. Horak, and M. Keller, Scientific Reports 7, 5556 (2017)

Q 44.4 Wed 15:00 K 1.013

Towards electrooptically controlled cavity QED with rare-

earth ion doped lithium niobate — •Thomas Kornher[1], Roman Kolesov[1], Kangwei Xia[2], Hans-Werner Becker[3], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universtät Stuttgart, Stuttgart, Germany — [2]Department of Physics, The Chinese University of Hong Kong, Hong Kong, China — [3]RUBION, Ruhr-Universitat Bochum, Bochum, Germany

Rare-earth ions doped into crystals are known for narrow optical transitions, long spin coherence times and optical access to their nuclear spins, which makes them suitable for quantum information storage applications. Boosting the emission rate of long-lived radiative transitions exhibited by rare-earth ions doped into solid hosts by means of micro-resonators can provide enhanced spin initialization for memory purposes and improved optical access down to the single ion level potentially. We present on-chip light matter interfaces composed of thin film lithium niobate disk resonators implantation-doped with Ytterbium ions. Measured devices show quality factors of over 10^5 in disk resonators with a mode volume of about $100^*(\lambda/n)^3$ and can be electrooptically controlled. We furthermore present experimental evidence of Purcell enhancement on the Yb $^2F_{7/2}$-$^2F_{5/2}$ transition at 980 nm.

Q 44.5 Wed 15:15 K 1.013

Coupling of SiV$^-$ ensemble in thin diamond membrane to fiber based microcavity — •Stefan Häussler[1], Richard Waltrich[1], Kerem Bray[2], Fedor Jelezko[1], Igor Aharonovich[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics and Center for Integrated Science and Technology, Ulm University, D-89081 Ulm, Germany — [2]School of Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, New South Wales 2007, Australia

On the route to the realization of various quantum technology applications like quantum repeaters solid-state quantum emitters such as color centers in diamond appear to be promising candidates. The remaining challenges like low rate of coherent photons, poor extraction efficiency out of the host material and low quantum yield especially in the case of the silicon-vacancy center can thereby be overcome using a resonant microcavity opening the possibility for a scalable use.

We show coupling of an ensemble of negatively charged silicon-vacancy (SiV$^-$) centers located in a thin (~ 200 nm) diamond membrane to a fiber-based microcavity at room temperature. The diamond membrane does not lead to significant scattering losses nor to formation of "diamond-like" cavity modes. Such hybrid systems enabling high cavity quality factors and at same time small mode volumes leading to improved optical properties and increased emission rate of the color centers. Further improvement of the cavity quality enables generation of photons with a high degree of indistinguishability from broadband emitter at room temperature.

Q 44.6 Wed 15:30 K 1.013

Polarization analysis of lasing from cold Ytterbium atoms — •Dmitriy Sholokhov, Hannes Gothe, Anna Breunig, and Jürgen Eschner — Universität des Saarlandes, Saarbrücken

We analyse the laser process from cold Ytterbium atoms that are magneto-optically trapped inside a 5 cm long high-finesse cavity. The atoms are laterally pumped to one of the three $^3P_1$ Zeeman sub levels and emit frequency-shifted light into the cavity. This lasing relies on a two photon process including trap light and was previously characterized for its power and frequency properties [1]. Here, we focus on the polarization dependence between pump and cavity output and infer information about the spatial position of the lasing atoms.

[1] H. Gothe et al., arXiv:1711.08707 (2017)

Q 44.7 Wed 15:45 K 1.013

Quenches across the self-organization transition in multimode cavities — Tim Keller[1], Valentin Torggler[2], •Simon B. Jäger[1], Stefan Schütz[1,3], Helmut Ritsch[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Institut für Theoretische Physik, Universität Innsbruck, A-6020 Innsbruck, Austria — [3]icFRC, IPCMS (UMR 7504) and ISIS (UMR 7006), University of Strasbourg and CNRS, 67000 Strasbourg, France

A cold dilute atomic gas in an optical resonator can be radiatively cooled by coherent scattering processes when the driving laser frequency is tuned close but below the cavity resonance. When sufficiently illuminated, moreover, the atoms' steady state undergoes a phase transition from a homogeneous distribution to a spatially organized Bragg grating. We characterize the dynamics of this self-ordering process in the semi-classical regime when distinct cavity modes with commensurate wavelengths are quasi-resonantly driven by laser fields via scattering by the atoms. The lasers are simultaneously applied and uniformly illuminate the atoms, their frequencies are chosen so that the atoms are cooled by the radiative processes, their intensity is either suddenly switched or slowly ramped across the self-ordering transition. Numerical simulations for different ramp protocols predict that the system exhibits long-lived metastable states, whose occurrence strongly depends on initial temperature, ramp speed, and number of atoms.

Q 45: Precision Spectroscopy V - highly charged ions (joint session A/Q)

Time: Wednesday 14:00–15:45 Location: K 1.016

Q 45.1 Wed 14:00 K 1.016

Ion sources and beamline of the ALPHATRAP *g*-factor experiment — •Tim Sailer[1,2], Ioanna Arapoglou[1,2], José R. Crespo López-Urrutia[1], Alexander Egl[1,2], Martin Höcker[1], Sandro Kraemer[1,2], Andreas Weigel[1,2], Robert Wolf[1,3], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik — [2]Fakultät für Physik und Astronomie, Universität Heidelberg — [3]ARC Centre of Excellence for Engineered Quantum Systems, School of Physics, The University of Sydney, NSW Australia

The Penning-trap experiment ALPHATRAP, located at the Max-Planck-Institut für Kernphysik in Heidelberg, aims to measure the g factor of bound electrons in highly charged ions (HCI) up to hydrogen-like $^{208}Pb^{81+}$. In the electrical field of the nucleus with a strength of the order of 10^{16} V/cm bound-state quantum electrodynamics can be tested with highest precision in extreme conditions. To enable measurements beyond the current thermal limits, laser-cooling will be implemented. To this end, a Laser Ion Source (LIS) based on a Nd:YAG laser is used to produce $^9Be^+$ ions, which will subsequently be laser cooled inside the trap using a 313nm laser system. HCI, which cannot be directly addressed by the laser, will be sympathetically cooled by the beryllium ions. The LIS is attached to the existing beamline, which allows an external production and injection of the $^9Be^+$ ions. Additionally, a table-top electron beam ion source has been used successfully to produce and inject ions up to $^{40}Ar^{13+}$ into the trap. Finally, the HD-EBIT will be connected to the experiment in the near future to enable the transfer and subsequent measurement of heavy HCI.

Q 45.2 Wed 14:15 K 1.016

SIM-X: Silicon Microcalorimeters for X-ray Spectroscopy at Storage Rings - Status and Perspectives — •Pascal Andree Scholz[1], Victor Andrianov[2], Artur Echler[3,4], Peter Egelhof[3,4], Oleg Kiselev[3], Saskia Kraft-Bermuth[1], and Damian Müll[1] — [1]Justus Liebig University Giessen, Germany — [2]Lomonosov Moscow State University, Russia — [3]GSI Helmholtz Center, Germany — [4]Johannes Gutenberg University Mainz, Germany

High-precision X-ray spectroscopy of highly-charged heavy ions provides a sensitive test of quantum electrodynamics in very strong Coulomb fields. However, one limitation of the current accuracy of such experiments is the energy resolution of available X-ray detectors. Due to their excellent energy resolution for X-ray energies around 100 keV, silicon microcalorimeters, based on silicon thermistors and tin absorbers, have already demonstrated their potential in previous experiments at the Experimental Storage Ring (ESR) of the GSI Helmholtz Center for Heavy Ion Research. Based on these experiments, a larger detector array with three times the active detector area in a cryogen-free cryostat equipped with a pulse tube cooler is currently in preparation. After a successful test experiment in june 2016 at the ESR with SIM-X, efforts in optimization and characterization concerning the thermal design and performance were made in order to improve the overall energy resolution and performance. In this presentation, we will present the current status of developments and perspectives in particular with respect to the next FAIR Phase 0 experiments.

Q 45.3 Wed 14:30 K 1.016

Commissioning of the ALPHATRAP double Penning-trap system — •Ioanna Arapoglou[1,2], Alexander Egl[1,2], Martin Höcker[1], Sandro Kraemer[1,2], Tim Sailer[1,2], Andreas Weigel[1,2], Robert Wolf[1], Sven Sturm[1], and Klaus Blaum[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Faculty of Physics and Astronomy, University of Heidelberg

The ALPHATRAP experiment is a state-of-the-art Penning-trap setup aiming for high-precision g-factor measurements on heavy highly charged ions (HCI), such as hydrogen-like $^{208}Pb^{81+}$. That way the most stringent test of bound-state quantum electrodynamics (BS-QED) can be carried out. The storage and manipulation of the ions is achieved using a double Penning-trap system in which the electron's g-factor is deduced from measuring the magnetic moment of the bound electron. The setup includes several ion creation possibilities for offline ion production, additional to the online injection of heavy HCI from the Heidelberg Electron Beam Ion Trap. The latter will deliver the ions of interest via an ion beam-line to the cryogenic double Penning-trap system, which is currently at the commissioning stage. Presently, proof-of-principle measurements are taking place in preparation for the first g-factor measurement. Among other things, necessary requirements for such a measurement will be the optimisation of the trapping potential, effective ion cooling, adiabatic ion transport as well as accurate knowledge of field inhomogeneities within the trapping region. These results and the current status of the experiment will be discussed.

Q 45.4 Wed 14:45 K 1.016

Progress of the MEDeGUN commissioning and extension of the TwinEBIS test bench — •Hannes Pahl[1,2], Martin Breitenfeldt[1], Alexander Pikin[1,3], Johanna Pitters[1], and Fredrik Wenander[1] — [1]CERN, 1211 Geneva 23, Switzerland — [2]Universität Heidelberg, 69120 Heidelberg, Germany — [3]Brookhaven National Laboratory, Upton 11973, USA

We report on recent results related to the commissioning of a Brillouin-type electron gun (MEDeGUN) at TwinEBIS, a test bench for the development of Electron Beam Ion Sources (EBIS) at CERN. MEDeGUN is developed for both nuclear research and medical applications. It combines a strong electrostatic compression of the electron beam inside the magnetically shielded gun with the conventional magnetic compression into the ionisation region, providing high current-density electron beams for rapid charge breeding. During the commissioning, a 10 keV electron beam of more than 1 A was successfully injected into a 2 T solenoid field with negligible losses.

In order to measure the charge breeding efficiency, an upgrade of the existing setup is required. Hence, the TwinEBIS setup will be extended with a low-energy ion beam line that allows for external ion injection and extraction. A number of diagnostic devices for the extracted ion bunches will be installed, and a gas feed will be added to enable neutral gas injection directly into the EBIS ionisation region. Here, we present the design of the beam line and modifications to MEDeGUN intended to be implemented for the next commissioning run.

Q 45.5 Wed 15:00 K 1.016

Electronic transitions in highly charged ions as X-ray wavelength standards — •Sven Bernitt[1,2], Steffen Kühn[2], René Steinbrügge[3], Hans-Christian Wille[3], Thomas Stöhlker[1,4], and José R. Crespo López-Urrutia[2] — [1]IOQ, Friedrich-Schiller-Universität, Jena, Germany — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Deutsches Elektronen-Synchrotron, Hamburg, Germany — [4]Helmholtz-Institut Jena, Germany

The newest generations of synchrotron and free-electron laser light sources combined with high resolution monochromators offer high X-ray photon fluxes over narrow bandwidths. This allows for a wide range of new applications, among others in material science, biophysics, laboratory astrophysics, and fundamental atomic physics. However, currently most experiments have to rely on crystallographic standards or absorption edges measured in macroscopic samples for the calibration of X-ray wavelengths, which limits the achievable accuracies. Electronic transitions in few-electron highly charged ions can serve as reliable high-precision alternative X-ray wavelength standards. We have developed PolarX-EBIT, a compact electron beam ion trap with a novel off-axis electron gun. It allows to measure resonantly excited fluorescence of highly charged ions interacting with X-rays without blocking the photon beam, therefore allowing wavelength calibration simultaneous with arbitrary downstream experiments. We present the new trap as well as the results of an experiment where it was used to provide an accurate calibration of the photoabsorption of various gases relevant for the interpretation of astropysical X-ray spectra.

Q 45.6 Wed 15:15 K 1.016

Recent laser cooling and laser spectroscopy experiments at the ESR — •Danyal Winters[1], Oliver Boine-Frankenheim[1,2], Axel Buss[3], Christian Egelkamp[3], Lewin Eidam[2], Volker Hannen[3], Zhongkui Huang[4], Daniel Kiefer[2], Sebastian Klammes[1,2], Thomas Kühl[1,5], Markus Löser[6,7], Xinwen Ma[4], Peter Spiller[1], Wilfried Nörtershäuser[2], Rodolfo Sanchez Alarcon[1], Ulrich Schramm[6,7], Mathias Siebold[6], Markus Steck[1], Thomas Stöhlker[1,5,8], Johannes Ullmann[3], Thomas Walther[2], Hanbing Wang[4], Weiqiang Wen[4], Christian Weinheimer[3], Daniel Winzen[3], and Michael Bussmann[6] — [1]GSI Darmstadt — [2]TU-Darmstadt — [3]Uni Münster — [4]IMP Lanzhou — [5]HI-Jena — [6]HZDR Dresden — [7]TU-Dresden — [8]Uni-Jena

One of the most promising techniques for ion beam cooling at relativistic energies, is laser cooling. The fluorescence emitted after laser excitation can be used for both optical beam diagnostics and precision spectroscopy. We present results on experiments with $^{12}C^{3+}$ beams (122 MeV/u) stored in the experimental storage ring (ESR) in Darmstadt, Germany. The cooling transition in the ions was excited using a pulsed laser system with a high repetition rate, and a wide-scanning cw laser system. A novel XUV detector system, installed inside the vacuum of the ESR, was used to detect the fluorescence from the ions. We will present the experimental setup and preliminary data, and give an outlook on future experiments at FAIR in Germany and HIAF in China.

Q 45.7 Wed 15:30 K 1.016

Commissioning of a detection system for forward emitted XUV photons at the ESR — M. Bussmann[1], A. Buss[2], C. Egelkamp[2], L. Eidam[3], V. Hannen[2], Z. Huang[4], D. Kiefer[5], S. Klammes[5], Th. Kühl[6,7,8], M. Loeser[1], X. Ma[4], W. Nörtershäuser[9], H.-W. Ortjohann[2], R. Sánchez[6,9], M. Siebold[1], Th. Stöhlker[6,7,10], J. Ullmann[7,9,10], J. Vollbrecht[2], Th. Walther[5], H. Wang[4], Ch. Weinheimer[2], D. Winters[6], and •D. Winzen[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf — [2]Institut für Kernphysik, WWU Münster — [3]Institut für Theorie Elektromagnetischer Felder, TU Darmstadt — [4]Institute of Modern Physics, CAS Lanzhou — [5]Institut für Angewandte Physik, TU Darmstadt — [6]GSI, Darmstadt — [7]Helmholtz-Institut Jena — [8]Institut für Physik, Uni Mainz — [9]Institut für Kernphysik, TU Darmstadt — [10]Institut für Optik und Quantenelektronik, Uni Jena

The Institut für Kernphysik in Münster developed an XUV-photon detection system for laser spectroscopy measurements at the ESR. In a test beam time for laser cooling with $^{12}C^{3+}$-ions at $\beta \approx 0.47$, the $^2S_{1/2} - {}^2P_{1/2}$ and the $^2S_{1/2} - {}^2P_{3/2}$ transitions were investigated to commission the system. The detector features a movable cathode plate which is brought into the vicinity of the beam to collect forward emitted Doppler shifted photons ($\lambda_{\mathrm{lab}} \approx 93$ nm). The photons produce mostly low energetic (<3 eV) secondary electrons which are electromagnetically guided onto an MCP detector. Preliminary results of the beam time will be presented. This work is supported by BMBF under contract number 05P15PMFAA.

Q 46: Quantum Information (Concepts and Methods) IV

Time: Wednesday 14:00–16:15 Location: K 1.019

Q 46.1 Wed 14:00 K 1.019

Steering criteria from general entropic uncertainty relations — •Ana Cristina Sprotte Costa, Roope Uola, and Otfried Gühne — Universität Siegen, Siegen, Germany

Steering is a term coined by Schrödinger in 1935 in order to capture the essence of the Einstein-Podolsky-Rosen argument. It describes Alice's ability to affect Bob's quantum state through her choice of a measurement basis, without allowing for instantaneous signalling. We investigate a steering criteria from general entropic uncertainty relations and demonstrate that the resulting criteria outperform existing criteria in several scenarios. In this talk, we present the application of these criteria for different classes of bipartite systems, e.g. isotropic states, general two-qubit systems, bound entangled states. We also discuss the extension of these criteria for the multipartite case.

Q 46.2 Wed 14:15 K 1.019

Hypergraph states are universal resource states for measurement-based quantum computation — •Mariami Gachechiladze[1], Akimasa Miyake[2], and Otfried Gühne[1] — [1]University of Siegen, Siegen, Gemrnay — [2]University of New Mexico, Albuqueqrue, NM, USA

Hypergraph states form a family of multiparticle quantum states that generalizes graph states. We derive and utilize Pauli measurement rules to show that hypergraph states are novel resource states for measurement-based quantum computation with only Pauli measurements, additionally offering new schemes to parallelize quantum computation.

Q 46.3 Wed 14:30 K 1.019

New no-go theorems regarding phase space negativity and contextuality as resources — •Felipe Montealegre Mora, Huangjun Zhu, and David Gross — University of Cologne, Cologne, Germany

It has been proven recently that both negativity in the discrete Wigner function and contextuality with respect to stabilizer measurements may be considered resources in several variants of the model of quantum computing with magic states. They are also known not to be resources when working over qubits, and when including all operations taken from the stabilizer world into the model. This is arguably the most relevant case, as quantum algorithms are commonly understood in this framework.

Here we derive two new no-go theorems extending the results above. The first result considers phase space representations, a wider class of representations than discrete Wigner functions. We show that no phase space representation is covariant with respect to the real Clifford group. This result implies that negativity also fails to be a resource in this wider context whenever all real Clifford unitaries are part of the computational model. The second result considers a set of Pauli measurements subject to a certain uniformity condition. It is shown that if such a measurement set is large enough, then it contains some Clifford transform of the Mermin-Peres square with high probability.

Q 46.4 Wed 14:45 K 1.019

Continuous phase-space representations for finite-dimensional quantum states and their tomography — •Balint Koczor, Robert Zeier, and Steffen J. Glaser — Technische Universität München, Garching, Germany

Continuous phase spaces have become a powerful tool for describing, analyzing, and tomographically reconstructing quantum states in quantum optics and beyond. A plethora of these phase-space techniques are known, however a thorough understanding of their relations was still lacking for finite-dimensional quantum states. We present a unified approach to continuous phase-space representations which highlights their relations and tomography. The quantum-optics case is then recovered in the large-spin limit. Our results will guide practitioners to design robust innovative tomography schemes.

Q 46.5 Wed 15:00 K 1.019

Quantum random walks with step dependent coins — •Shahram Panahiyan[1] and Stephan Fritzsche[1,2] — [1]Helmholtz-Institut Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Germany

A quantum random walk is a promising concept for simulating other quantum systems, developing quantum algorithms and exploring topological phases [1]. For these purposes, controllability over walker's probability density distribution is desired. Here, we study a particular type of quantum random walk which has a step dependent coin. It will be shown that with this setup, the walker could have diverse probability density distribution ranging from a complete localization to ballistic spread.

We have also investigated the Shannon entropy of this walk. The Shannon entropy is a tool for measuring the amount of uncertainty that is present in the state of a physical system [2]. This quantity could be used to determine the modification in amount of information of a physical system that goes through a process. It will be shown and explained how a rather irregular behavior arises for entropy of walks with a step dependent coin.

[1]: T. Kitagawa et al., Phys. Rev. A 82, 033429 (2010).

[2]: M. A. Nielsen et al., *Quantum computation and quantum information* (Cambridge University Press, 2010).

Q 46.6 Wed 15:15 K 1.019

Optimal catalytic quantum randomness — •Paul Boes, Henrik Wilming, Rodrigo Gallego, and Jens Eisert — Freie Universität Berlin

We investigate how much randomness is necessary to bring a system from one state to another state that is majorized by the initial one. We solve the problem completely by providing an optimal protocol showing that a maximally mixed state with dimension square-root of the system dimension is in general necessary and sufficient to implement such a state transition. The process we construct has the additional feature that the source of randomness is catalytic, i.e., remains in the maximally mixed state and can hence be re-used for different systems. We turn to considering several applications of this result, ranging from problems in decoherence and minimal measurement systems over scrambling of information to notions of cryptography. In particular, we introduce a novel cryptographic protocol, somewhat similar to superdense coding, with which two parties can communicate two classical bits securely over a public quantum channel of two qubits and a single private shared ebit. The protocol has the advantage that the ebit, after the two classical bits have been securely transmitted, returns exactly to its initial state and can be re-used to transmit further classical information securely. We also sketch how similar techniques can be used to establish a novel secret sharing scheme, where a given classical message can only be decoded if all parties of a given group consent. We complement the exact analysis of pinching maps with a discussion of approximate protocols based on quantum expanders.

Q 46.7 Wed 15:30 K 1.019

Recovery of quantum gates from few average gate fidelities — •Ingo Roth[1], Richard Kueng[2], Shelby Kimmel[3], Yi-Kai Liu[4], Jens Eisert[1], and Martin Kliesch[5] — [1]FU Berlin, Germany — [2]CalTech, USA — [3]Middlebury College, USA — [4]NIST, Gaithersburg, USA — [5]University of Gdańsk, Poland

One of the core tasks in quantum information science is the characterisation of quantum processes. But achieving this characterisation efficiently and accurately is a challenge. In this work, we consider using data from average gate fidelities to characterize quantum gates. Average gate fidelities are relatively easy to learn, and in some cases have additional robustness to state preparation and measurement errors. We show that any unital quantum channel can be affinely expanded in terms of any given unitary 2-design with coefficients determined by the average gate fidelities. Therefore $\mathcal{O}(d^4)$ average gate fidelities allow to uniquely determine a unital quantum channel acting on a d-dimenisonal Hilbert space. For the important case of characterizing multi-qubit unitary gates, we can further reduce this number to $\mathcal{O}(d^2 \log(d))$ average fidelities measured with respect to random Clifford gates, which are natural for many experiments. As a side result, we also obtain a novel statistical interpretation of the unitarity – a figure of merit that characterises the coherence of a noise process.

In our proofs we exploit new representation theoretic insights on the Clifford group, develop a version of Collins' calculus with Weingarten functions for integration over the Clifford group, and combine this with proof techniques from compressed sensing.

Q 46.8 Wed 15:45 K 1.019

Artificial Neural Network Representation of Spin Systems in a Quantum Critical Regime — •Stefanie Czischek, Martin Gärttner, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

We use the newly developed artificial-neural-network (ANN) representation of quantum spin-$\frac{1}{2}$ states based on restricted Boltzmann machines to study the dynamical build-up of correlations after sudden quenches in the transverse-field Ising model. We calculate correlation lengths and study their time evolution after sudden quenches from a large initial transverse field to different distances from the quantum critical point. By comparison with exact numerical solutions we show that in the close vicinity of the quantum critical point, where large correlations and volume-law entanglement are found, large network sizes are necessary to capture the exact dynamics. On the other hand we show a high accuracy of the network representation for quenches further away from the quantum critical point even for small network sizes scaling linearly with the system size. In these regimes the ANN representation shows promising results which suggest that the method may be efficiently used for not exactly solvable systems in one or higher dimensions.

Q 46.9 Wed 16:00 K 1.019

The static correlation paradox in quantum chemistry: a quantum information approach — Carlos Benavides-Riveros[1], Christian Schilling[2], and •Zoltán Zimborás[3] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle (Saale), Germany — [2]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom — [3]Wigner Research Centre for Physics, H-1525 Budapest, Hungary

In many scenarios in quantum chemistry, e.g., dissociation of molecules, there is only an asymptotically small interaction between different electrons, yet the ground state is very far from being a Slater determinant, i.e., an uncorrelated state. In this talk, we will treat this problem from a quantum information theoretic point of view. Giving first the proper definitions of different types of correlations (particle and mode correlations), taking also into account the parity and the particle-number superselection rules, we show that in this scenarios even a very small noise or temperature would make the state uncorrelated. Discussing the implication of this, we note that the result implies that in realistic set-ups the strong correlation of the state disappears, which may also hint to the possibility of improved numerical methods that can capture these scenarios.

Q 47: Quantum Information (Quantum Repeater)

Time: Wednesday 14:00–16:00 Location: K 1.020

Group Report Q 47.1 Wed 14:00 K 1.020

High-fidelity entanglement between a trapped ion and a telecom photon via quantum frequency conversion — •Matthias Bock, Pascal Eich, Stephan Kucera, Matthias Kreis, Andreas Lenhard, Christoph Becher, and Jürgen Eschner — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

Entanglement between a stationary quantum system and a photonic flying qubit is an essential ingredient of a quantum-repeater network. Most stationary quantum bits, however, have transition wavelengths in the blue, red or near-infrared spectral regions, whereas long-range fiber-communication requires wavelengths in the low-loss, low-dispersion telecom regime. A proven tool to interconnect flying qubits at visible/NIR wavelengths to the telecom bands is quantum frequency conversion.

Here we present a complete device that produces entangled states between an atomic Zeeman qubit in a single trapped $^{40}Ca^+$ ion and the polarization state of a telecom photon with a Bell-state fidelity of $98.2 \pm 0.2\%$. We achieve this by combining a trapped-ion quantum node producing ion-photon entanglement with a fidelity of $98.3 \pm 0.3\%$ and a polarization-preserving frequency converter connecting 854 nm to the telecom O-band. The converter, realized by difference-frequency generation in a PPLN waveguide embedded in single-crystal Mach-Zehnder-interferometer, combines $99.75 \pm 0.18\%$ process fidelity for the polarization-state conversion, 26.5% external conversion efficiency and 11.4 photons/s conversion-induced unconditional background.

Q 47.2 Wed 14:30 K 1.020

Atom-to-photon quantum-state transfer for quantum networks — •Pascal Eich, Matthias Bock, Stephan Kucera, Andreas Lenhard, Christoph Becher, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Quantum interfaces between atomic nodes and photonic quantum channels are crucial building blocks for single-atom-based quantum networks. In previous work, we demonstrated the quantum-state transfer from a single photon at 854 nm onto the electronic state of a single trapped $^{40}Ca^+$ ion [1]. Here we demonstrate the inverse mapping, of an atomic quantum state onto the polarization state of a single 854-nm photon. This experiment completes our fully bi-directional atom-photon quantum interface that provides compatibility with low-loss telecom-fiber communication through polarization-preserving quantum frequency conversion (QFC) [2].

[1] S. Kucera et al., DPG-Verhandlungen 2017, Q 2.5
[2] M. Bock et al., arXiv:1710.04866 (2017)

Q 47.3 Wed 14:45 K 1.020

A Gate between Two Matter Qubits Using Cavity QED — •Severin Daiss, Stephan Welte, Bastian Hacker, Lin Li, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Cavity QED systems have been established as an ideal interface to connect flying and stationary qubits in a future quantum network. Exchange of photons between the resonator-based network nodes enables the distribution of quantum states and the generation of remote entanglement [1]. To build a scalable network architecture, each node is required to contain several qubits that are connected by quantum gate operations. To this end, we have trapped two neutral atoms inside an optical cavity so that they are both strongly coupled to light impinging onto the resonator [2]. In this setup, we realize a quantum gate between two atomic qubits by reflecting an optical photon that arrives via the network channel. We show the functionality of our gate as a CNOT and demonstrate its entangling capabilities on the two atoms. The presented mechanism offers perspectives towards one-step many-atom gates or hybrid gates between several atoms and a network photon.

[1] A. Reiserer, G. Rempe, Rev. Mod. Phys. 87, 1379 (2015).
[2] S. Welte, B. Hacker, S. Daiss, S. Ritter, G. Rempe, Phys. Rev. Lett. 118, 210503 (2017).

Q 47.4 Wed 15:00 K 1.020

Remote two-photon interference at 1550 nm via quantum frequency conversion of quantum dot photons — •Benjamin Kambs[1], Jonas Heinrich Weber[2], Jan Kettler[2], Simon Kern[2], Matthias Bock[1], Hüseyin Vural[2], Simone Luca Portalupi[2], Michael Jetter[2], Christoph Becher[1], and Peter Michler[2] — [1]Universität des Saarlandes, Naturwissenschaftlich-Technische Fakultät, Campus E2.6, 66123 Saarbrücken, Germany — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Research Centers SCoPE und IQ^{ST}, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Quantum repeaters constitute a major milestone in establishing fiber-based quantum networks. Ideally, such networks are built upon a pool of identical emitters providing indistinguishable telecom photons. However, the achieved two-photon interference (TPI) visibilities of solid state telecom quantum emitters fall short of corresponding systems at shorter wavelengths so far. Moreover, solid state sources typically show mismatched emission frequencies and need to be tuned into resonance. Here we employ efficient quantum frequency down-conversion (QFDC) to meet both prerequisites: near infrared photons emitted by two distinct semiconductor quantum dots are transferred to a common wavelength in the telecom C-band. Subsequently testing their mutual indistinguishability, we obtain a TPI visibility of 25 % solely limited by spectral diffusion. Our results show that QFDC can be used to integrate state-of-the-art emitters into quantum networks and thus constitute a basic building block of quantum repeaters.

Q 47.5 Wed 15:15 K 1.020

Towards efficient quantum memories at telecom wavelength — Benjamin Merkel, Lorenz Weiss, Natalie Wilson, Valentin Crépel, Andreas Gritsch, and •Andreas Reiserer — MPI of Quantum Optics, Garching, Germany

Global-scale quantum networks require efficient interfaces between long-lived memory nodes and photons at a telecommunications wavelength, where loss in optical fibers is minimal. In this context, Erbium ions doped into suited crystals are a promising candidate, as they exhibit a coherent optical transition at 1.5 μm and spin lifetimes exceeding 100 ms. Unfortunately, such long coherence times require a low dopant concentration to avoid ion-ion interactions, which puts a limit on the achievable efficiency of quantum memories. In our group, we plan to overcome this challenge by embedding Erbium-doped crystals into high-finesse optical resonators. In initial experiments with crystals of low dopant ion concentration, we have observed spin lifetimes of up to 0.5 s. By applying microwave pulses, we explore the potential of dynamical decoupling to extend the coherence time to this lifetime limit. In addition, we investigate the use of nuclear spins as a route to longer memory times. Finally, we have inserted Erbium-doped crystals into optical cavities that give access both to the single-ion Purcell regime and to the collective strong coupling regime. This opens unique perspectives for the implementation of efficient quantum memories for telecom photons.

Q 47.6 Wed 15:30 K 1.020

An atomic memory suitable for semiconductor quantum dot single photons — •Roberto Mottola, Andrew Horsley, Gianni Buser, Janik Wolters, Lucas Béguin, Jan-Philipp Jahn, Richard Warburton, and Philipp Treutlein — Universität Basel, Switzerland

Quantum networks have been proposed to overcome current limitations in quantum communication and computing. A promising path to realize these networks is the heterogeneous quantum node approach. Each node consists of separate and thus individually optimizable physical systems to generate and store single photons.

Pursuing the heterogeneous approach we demonstrated a quantum memory in warm Rb vapor with on-demand storage and retrieval [1] that in principle is compatible to semiconductor quantum dot photons. Using attenuated laser pulses on the single-photon level with a 660MHz linewidth, we have achieved an end-to-end efficiency $\eta_{e2e} = 3.4(3)\%$ for a storage time of $T = 50$ns and an intrinsic storage and retrieval efficiency $\eta = 17(3)\%$. We are working to further improve the performance of our memory by applying a tesla-order magnetic field, entering the Paschen-Back regime, where the separation of atomic ground state hyperfine sublevels is larger than the optical linewidth. We will be able to optically address each sublevel individually, allowing us to engineer an almost ideal atomic three-level system. This will get rid of spurious single photon absorption and suppress noise due to four-wave mixing, enhancing the efficiency and signal-to-noise ratio of the memory.

[1] J. Wolters, et al., Phys. Rev. Lett. 119, 060502 (2017)

Q 47.7 Wed 15:45 K 1.020

Device-independent Secret Key Rate Analysis for Quantum Repeaters — •Timo Holz, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine University, Duesseldorf, Germany

The device-independent approach to quantum key distribution (QKD) aims to establish a secret key between two or more parties with untrusted devices, potentially under full control of a quantum adversary. The performance of a QKD protocol can be quantified by the secret key rate, which is linked to the violation of an appropriate Bell-inequality in a setup with untrusted devices. We study secret key rates in the device-independent scenario for different quantum repeater setups and compare them to their device-dependent analogon. The quantum repeater setups under consideration are the original protocol by Briegel *et al.* and the hybrid quantum repeater protocol by van *Loock et al.*. The secret key rate depends on a variety of parameters, such as the gate quality or the detector efficiency. We systematically analyze the impact of these parameters and suggest optimized strategies.

[1] T. Holz, H. Kampermann, and D. Bruß, arXiv:1711.06072 (2017)

Q 48: Quantum Gases (Fermions) III

Time: Wednesday 14:00–16:15 Location: K 1.022

Q 48.1 Wed 14:00 K 1.022

Dynamics in the dissipative Fermi-Hubbard model — •Koen Sponselee[1], Benjamin Abeln[1], Marcel Diem[1], Maximilian Hagenah[1], Bodhaditya Santra[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Excellent isolation from environmental influences is a key requirement of many quantum physics experiments, because dissipation usually leads to decoherence in the quantum world. Counter-intuitively, certain types of dissipation can also drive a quantum system into a highly entangled steady state and are thus useful for quantum state preparation.

Here we report on the realization of the one-dimensional dissipative Fermi Hubbbard model exploiting strong two-body loss processes occurring in excited state collisions of ^{173}Yb atoms. Starting from a Mott-insulating state we induce non-equilibrium dynamics leading to strong initial particle loss. Strikingly, after a transient time, this loss is largely suppressed, which we attribute to the build-up of correlations. Our measurements indicate the formation of highly entangled fermionic many-body states, which could be useful for metrology or quantum simulation.

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

Q 48.2 Wed 14:15 K 1.022

Non-Equilibrium Mass Transport in the 1D Fermi-Hubbard Model — •Sebastian Scherg[1,2], Thomas Kohlert[1,2], Henrik Lüschen[1,2], Pranjal Bordia[1,2], Jan Stolpp[1], Jacek Herbrych[3,4], Fabian Heidrich-Meisner[1], Ulrich Schneider[5], Monika Aidelsburger[1,2], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstr. 4, 80799 Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [3]Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA — [4]Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA — [5]Cavendish Laboratory, University of Cambridge, J.J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom

We experimentally and numerically investigate the sudden expansion of interacting Fermions in a one-dimensional lattice. Focusing on initial states with more than half filling, we observe a phase separation of singlons (quickly expanding particles on singly occupied lattice sites) and doublons (slow particles on doubly occupied lattice sites). We discuss evidence of quantum distillation in the limit of large interactions, occuring if singlons distill out of the doublon cloud, leading to a contraction of the doublon region in the cloud. For initial states with less than half filling, we find a phase of singlons expanding nearly independently of the interaction strength, which is in contrast to the behavior of Bosons. We attribute the weak effect of interactions to a less efficient generation of dynamical doublons due to the Pauli principle.

Q 48.3 Wed 14:30 K 1.022

Microscopic confirmation of fluctuation relations in Hubbard chains — •Timon Hilker[1], Guillaume Salomon[1], Joannis Koepsell[1], Jayadev Vijayan[1], Michael Höse[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institute für Quantenoptik, Garching — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, München

Fluctuation-dissipation relations express fundamental connections between the equilibrium fluctuations of a system, its linear response to an external force and its temperature. Here, we present an experimental confirmation of such a relation for Fermi-Hubbard chains with ultracold ^{6}Li atoms by measuring density-fluctuations, compressibility and temperature simultaneously. With our quantum gas microscope, we have access to all three contributions including the crucial non-local fluctuations between all pairs of sites. Conversely, the relation provides a robust method for a theory-independent measurements of a system's temperature even at strong interactions.

Q 48.4 Wed 14:45 K 1.022

Towards realizing small Fermi-Hubbard type systems atom by atom — •Phillip Wieburg, Martin Schlederer, Thomas Lompe, and Henning Moritz — Institut für Laser-Physik, Universität Hamburg

The development of quantum gas microscopes has enabled the study ultracold atoms in optical lattices with single site, single atom resolution. In these experiments, the gases are typically cooled evaporatively and loaded into a large optical lattice formed by interfering laser beams. Here, we will report on the present status of an experimental setup designed to follow a complementary approach [1] where small Fermi-Hubbard type systems are assembled site by site using optical microtraps.

We have lasercooled K40 atoms to sub-Doppler temperatures using magneto-optical trapping and grey molasses cooling. After magnetic transport to the science region the atoms are loaded into optical lattices for further Raman-sideband cooling. Our setup features two high NA in-vacuo microscopes which will be used to create small scale structures such as 2x2 site plaquettes and to image the atoms. The technique combines fast experimental cycle times with single site addressability and detection and will allow to study the fundamental processes governing the Fermi-Hubbard model in a bottom-up approach.

[1] A.M. Kaufman et al., Physical Review X 2, 041014 (2012).

Q 48.5 Wed 15:00 K 1.022

Detection of Entanglement in a Fermi-Hubbard Dimer — •Andrea Bergschneider, Vincent Klinkhamer, Ralf Klemt, Jan Hendrik Becher, Gerhard Zürn, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg

Entanglement is a defining feature of quantum many-body states and can be used to characterize quantum phases. In itinerant systems, where entanglement emerges naturally through coherent particle motion and interactions, it is notoriously challenging to detect experimentally.

We probe the presence of entanglement in the fundamental unit cell of the Fermi-Hubbard model. Using fermionic Lithium 6 in optical microtraps, we deterministically realize quantum states in a tunable double-well potential. These states are characterized by their spin- and particle resolved correlation functions in position and in momentum space. We observe strong correlations in both degrees of freedom, indicating the high coherence of the two-particle system. We establish witness criteria to certify the presence of entanglement in the Fermi-Hubbard dimer and separately observe the emergence of entanglement between modes and between particles.

Q 48.6 Wed 15:15 K 1.022

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

We report evidence for spin-rotation (SR) coupling in an ultracold mixture of fermionic ^{6}Li and bosonic ^{133}Cs by magnetic field dependent atom-loss spectroscopy. For the p-wave (l = 1) Feshbach resonances we observe a triplet structure of different m_l components. We attribute the splitting of the $m_l = \pm 1$ component to electronic SR coupling. The size of the SR coupling constant in the highest vibrational state of LiCs is determined to be $|\gamma| = 0.000566(50)$ in units of the effective rotational constant. The SR-induced splitting is estimated for all other bialkali systems, suggesting that SR coupling has to be considered when classifying the p-wave superfluid phases in spin-polarized fermions.

Q 48.7 Wed 15:30 K 1.022

Design and characterization of a quantum heat pump in a driven quantum gas — •Arko Roy, Daniel Vorberg, and André Eckardt — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany.

We propose a novel scheme for quantum heat pumps powered by rapid time-periodic driving. We focus our investigation on a system consisting of two coupled driven quantum dots in contact with fermionic reservoirs at different temperatures. Such a configuration can be realized in a quantum-gas microscope. Theoretically we characterize the device by describing the coupling to the reservoirs using the Floquet-Born-Markov approximation.

Q 48.8 Wed 15:45 K 1.022

Tuning the Drude Weight of Dirac-Weyl Fermions in One-Dimensional Ring Traps — Manon Bischoff[1], Johannes Jünemann[1,2], Marco Polini[3], and •Matteo Rizzi[1] — [1]Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany — [2]Graduate School Materials Science in Mainz, Mainz, Germany — [3]Istituto Italiano di Tecnologia, Graphene Labs, Genova, Italy

We study the response to an applied flux of an interacting system of Dirac-Weyl fermions confined in a one-dimensional (1D) ring. Combining analytical calculations with density-matrix renormalization group results, we show that tuning of interactions leads to a unique many-body system that displays either a suppression or an enhancement of the Drude weight – the zero-frequency peak in the ac conductivity – with respect to the non-interacting value. An asymmetry in the interaction strength between same- and different-pseudospin Dirac-Weyl fermions leads to Drude weight enhancement. Viceversa, symmetric interactions lead to Drude weight suppression. Our predictions can be tested in mixtures of ultracold fermions in 1D ring traps.

Ref.: Bischoff, *et al.*, arXiv:1706.02679v1

Q 48.9 Wed 16:00 K 1.022

The resonant state at filling factor 1/2 in chiral fermionic ladders — •Andreas Haller[1], Matteo Rizzi[1], and Michele Burrello[2] — [1]Institute of Physics, Johannes Gutenberg University, 55099 Mainz, Germany — [2]Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

Helical liquids have been experimentally detected in both nanowires and ultracold atomic chains as the result of strong spin-orbit interactions. In both cases the inner degrees of freedom can be considered as an additional space dimension, providing an interpretation of these systems as synthetic ladders, with artificial magnetic fluxes determined by the spin-orbit terms. In this work, we analyze such a quasi-one-dimensional ladder geometry and characterize the helical state which appears at filling factor 1/2. This state is generated by a gap arising in the spin sector of the corresponding Luttinger liquid and can be interpreted as the one-dimensional (1D) limit of a fractional quantum Hall state of bosonic pairs of fermions. We study its main features, focusing on entanglement properties and correlation functions and support our analytic results with matrix product state simulations.

Q 49: Precision Measurements and Metrology (Atom Interferometry) (joint session Q/A)

Time: Wednesday 14:00–15:30 Location: K 2.013

Group Report Q 49.1 Wed 14:00 K 2.013

Probing the forces of blackbody radiation and dark energy with matter waves — •Philipp Haslinger[1], Vitkoria Xu[1], Matt Jaffe[1], Osip Schwartz[1], Paul Hamilton[2], Benjamin Elder[3], Justin Khoury[3], Matthias Sonnleitner[5], Monika Ritsch-Marte[4], Helmut Ritsch[5], and Holger Müller[1] — [1]UC Berkeley, USA — [2]UC Los Angeles, USA — [3]UPenn, USA — [4]Med-Uni Innsbruck, AUT — [5]Uni Innsbruck, AUT

In this talk I will give an overview of our recent work using an optical cavity enhanced atom interferometer to sense with gravitational strength for fifths forces and for an on the first-place counterintuitive inertial property of blackbody radiation. Blackbody (thermal) radiation is emitted by objects at finite temperature with an outward energy-momentum flow, which exerts an outward radiation pressure. At room temperature e.g. a Cs atom scatters on average less than one of these photons every 10^8 years. Thus, it is generally assumed that any scattering force exerted on atoms by such radiation is negligible.

However, particles also interact coherently with the thermal electromagnetic field and this leads to a surprisingly strong force acting in the opposite direction of the radiation pressure.

If dark energy, which drives the accelerated expansion of the universe, consists of a screened scalar field (e.g. chameleon models) it might be detectable as a "5th force" using atom interferometric methods. By sensing the gravitational acceleration of a 0.19kg in vacuum source mass, we reach a natural bound for cosmological motivated scalar field theories and were able to place tight constraints.

Q 49.2 Wed 14:30 K 2.013

Matter waves optics with a space-borne Bose-Einstein condensate experiment — •Dennis Becker[1], Ernst M. Rasel[1], Wolfgang Ertmer[1], and the QUANTUS Team[1,2,3,4,5,6,7,8] — [1]IQ, Leibniz Universität Hannover — [2]HU Berlin — [3]JGU Mainz — [4]FBH Berlin — [5]U Ulm — [6]ZARM Bremen — [7]DLR — [8]TU Darmstadt

Atom interferometers are reaching an exquisite performance and expected to be sensitive probes of fundamental interactions. Thanks to the clean environment and long observation times possible, space promises to unfold the full potential of such sensors. In this contribution, we report on the first realization of a cold atom experiment in space achieved by the sounding rocket mission MAIUS-1. Within 6 min of micro-g and 81 experiments, the chip-based BEC machine demonstrated a high degree of stability and a good agreement with quantum gases models. These results are a key milestone towards BEC-based space missions aiming for gravimetry, gradiometry, tests of fundamental physics laws or the detection of gravitational waves.

QUANTUS & MAIUS are supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers DLR 50WM 1131-1137.

Q 49.3 Wed 14:45 K 2.013

New developments with the Gravimetric Atom Interferometer GAIN — •Bastian Leykauf[1], Anne Stiekel[1], Vladimir Schkolnik[1], Christian Freier[1], Hartmut Wziontek[2], Axel Rülke[2], Markus Krutzik[1], and Achim Peters[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Bundesamt für Karthographie und Geodäsie (BKG)

GAIN uses the interference of cold atoms to precisely and accurately measure temporal changes in the gravitational acceleration [1].

In cooperation with the German Federal Agency for Cartography and Geodesy (Bundesamt für Karthographie und Geodäsie, BKG), we conducted a measurement campaign at the geodetic observatory in Wettzell. We will report on the results of this measurement campaign, including the study of active and passive vibration isolation strategies as well as common-mode noise suppression by differential gravity measurements using two atomic samples. We will furthermore discuss systematic effects in the measured gravity value caused by residual magnetic fields [2] and higher order light-shifts.

[1] Freier et al. *Mobile quantum gravity sensor with unprecedented stability*, Journal of Physics: Conference Series **723** (2016)
[2] Hu et al. *Mapping the absolute magnetic field and evaluating the quadratic Zeeman-effect-induced systematic error in an atom interferometer gravimeter*, Physical Review A **96**, 033414 (2017)

Q 49.4 Wed 15:00 K 2.013

Large momentum transfer in a dual lattice configuration — •Matthias Gersemann[1], Sven Abend[1], Christian Schubert[1], Martina Gebbe[2], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU zu Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Bose-Einstein condensates (BEC) in combination with large momentum transfer beam splitters are a key component for future infrasound atomic gravitational wave detectors. For this reason we developed a new method for symmetric scalable large momentum separation using the combination of double Bragg diffraction and Bloch oscillations in a dual-lattice configuration. The basic principle consists of an initial splitting via Double Bragg diffraction and a subsequent acceleration by Bloch oscillations. This sequence enables the transfer of up to $1008\,\hbar k$ in a single beam splitter and $408\,\hbar k$ when implemented in an atom interferometer, limited by technical constraints. Further perspectives and limits are investigated and already show that this technique is also applicable for sensitivity enhancements of devices with smaller scales.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant number DLR 50WM1552-1557 (QUANTUS-IV-Fallturm), the Deutsche Forschungsgemeinschaft (DFG) in the scope of the SFB 1128 geo-Q and "Niedersächsisches Vorab" through QUANOMET.

Q 49.5 Wed 15:15 K 2.013

The linear potential and the cubic phase — •Matthias Zimmermann[1], Maxim A. Efremov[1], Albert Roura[1], Wolfgang P. Schleich[1], Arvind Srinivasan[2], Jon P. Davis[3], Frank A. Narducci[4], Sam A. Werner[5], and Ernst M. Rasel[6] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Germany — [2]Naval Air Systems Command, EO Sensors Division, Patuxent River, USA — [3]AMPAC, North Wales, USA — [4]Naval Postgraduate School, Monterey, USA — [5]Physics Laboratory, NIST, Gaithersburg, USA — [6]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

The quantum mechanical propagator of a massive particle in a linear gravitational potential is well-known to contain a phase φ_g scaling with the third power of propagation time T. This phase has the remarkable feature of being proportional to the ratio m_g^2/m_i, where m_g and m_i denote the gravitational and the inertial mass of the particle, respectively.

We propose an experiment to observe this phase using an atom interferometer [1]. For this purpose, we prepare two different accelerations g_g and g_e for the ground and excited state of the atom. In this way the atom accumulates two different phases $\varphi_g^{(g,e)}$ depending on its internal state and the total interferometer phase scales as T^3.

[1] M. Zimmermann et al., *Appl. Phys. B* **123**:102 (2017)

Q 50: Quantum Gases (Bosons) V

Time: Wednesday 14:00–16:00 Location: K 2.020

Q 50.1 Wed 14:00 K 2.020

Detecting genuine multipartite entanglement in a spatially extended Bose-Einstein condensate — •Philipp Kunkel, Maximilian Prüfer, Helmut Strobel, Daniel Linnemann, Anika Frölian, Thomas Gasenzer, Martin Gärttner, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg

The ability to produce genuine multipartite entangled states between addressable modes is a prerequisite for engineering states relevant for quantum information tasks such as measurement based quantum computation. We use contact interactions in a tightly confined Bose-Einstein condensate of ^{87}Rb to generate an entangled state of indistinguishable particles in a single mode. Subsequent expansion of the atomic cloud in a shallow waveguide potential distributes this entanglement spatially making it addressable via local operations. We verify Einstein-Podolsky-Rosen steering between distinct regions of the expanded atomic cloud by analyzing the correlations between different parts of the absorption image. We show that bipartite steering serves as a witness for genuine multipartite entanglement. With this we demonstrate genuine up to 5-partite entanglement in the elongated condensate.

Q 50.2 Wed 14:15 K 2.020

Many-body interference in a bosonic Josephson junction — •Gabriel Dufour[1,2], Jasper Dohse[1], Tobias Brünner[1], Alberto Rodríguez[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität-Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität-Freiburg, Albertstraße

19, D- 79104 Freiburg, Germany

The interference of two photons on a balanced beamsplitter reveals their mutual degree of indistinguishability, with the probability of measuring one photon in each output mode going from zero if the photons are identical, to one half if they are fully distinguishable, as demonstrated in the Hong-Ou-Mandel experiment [1]. We extend this line of thought to the case of many interacting bosons trapped in a double-well potential and study how the evolution is affected when the bosons can be distinguished through an internal degree of freedom. Based on the structure of the underlying many-body Hilbert space, we identify dynamical signatures of the initial state's degree of distinguishability both in the weakly and strongly interacting regimes [2,3].

[1] C.K. Hong, Z.Y. Ou, L. Mandel, Phys. Rev. Lett. 59, 2044 (1987)

[2] G. Dufour, T. Brünner, C. Dittel, G. Weihs, R. Keil, A. Buchleitner, arXiv:1706.05833 (2017), to appear in NJP

[3] T. Brünner, G. Dufour, A. Rodríguez, A. Buchleitner, arXiv:1710.08876 (2017)

Q 50.3 Wed 14:30 K 2.020

Entanglement between two spatially separated atomic modes — •Alexander Idel[1], Karsten Lange[1], Jan Peise[1], Bernd Lücke[1], Ilka Kruse[1], Guiseppe Vitagliano[2,3], Iagoba Apellaniz[3], Matthias Kleinmann[1], Géza Tóth[3,4,5], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences — [3]Department of Theoretical Physics, University of the Basque Country UPV/EHU — [4]IKERBASQUE, Basque Foundation for Science — [5]Wigner Research Centre for Physics, Hungarian Academy of Sciences

Large ensembles of ultra-cold atoms offer the possibility to generate an unprecedented level of multi-particle entanglement. However, the creation relies on the fundamental indistinguishability of the particles. Entanglement between spatially addressable systems is required for most applications in the field of quantum information. We employ spin changing collisions in a ^{87}Rb BEC to generate entanglement. By utilizing the natural mode structure of the spin resonances we show entanglement between two spatially separated modes. We prove the entanglement between the modes with a novel criterion, which accounts for imperfections of the state preparation, e.g. varying atom numbers in our condensate and the imperfect symmetry of the state.

Q 50.4 Wed 14:45 K 2.020

Periodic Quantum Rabi Model with Ultracold Rubidium Atoms in an Optical Lattice — •Johannes Koch[1], Trim Kasabaci[1], Martin Leder[1], Simone Felicetti[2], Enrique Rico[3,4], Carlos Sabin[5], Enrique Solano[3,4], and Martin Weitz[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, D-53115 Bonn, Germany — [2]Laboratoire Matériaux et Phénomènes Quantiques, Sorbonne Paris Cité, Université Paris Diderot, CNRS UMR 7162, 75013, Paris, France — [3]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, E-48080 Bilbao, Spain — [4]IKERBASQUE, Basque Foundation for Science, Maria Diaz de Haro 3, E-48013 Bilbao, Spain — [5]Instituto de Física Fundamental, CSIC, Serrano 113-bis, E-28006 Madrid, Spain

The quantum Rabi model describing the interaction between a two-level quantum system and a single bosonic mode has been thoroughly studied in the moderate and strong coupling regimes. Here we investigate the model in the deep strong coupling regime, where a pattern of collapse and revival of the initial quantum state is expected. Our experimental implementation to simulate the quantum Rabi model uses ultracold rubidium atoms in a tailored optical lattice potential, with the two-level system being represented by the occupation of Bloch bands of the lattice. This effective qubit interacts with a quantum harmonic oscillator provided by an optical dipole potential. Using atom interferometric techniques, the revival of the phase imprinted initial state is observed. The present status of the experiment will be presented.

Q 50.5 Wed 15:00 K 2.020

Al'tshuler-Aronov-Spivak oscillations of coherent bosonic matter-wave beams in the presence of interaction — •Renaud Chrétien[1], Josef Rammensee[2], Cyril Petitjean[1], and Peter Schlagheck[1] — [1]CESAM research unit, University of Liege, 4000 Liège, Belgium — [2]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

We theoretically study the propagation of a guided atom laser across an Aharonov-Bohm ring exposed to a synthetic gauge field. The presence of disorder within the ring gives rise to Al'tshuler-Aronov-Spivak oscillations [1], seen in the disorder-averaged transmission as a function of the effective gauge flux that is contained within the ring. Those oscillations are induced by coherent backscattering and represent a manifestation of weak localization. Through analytical and numerical calculations based on the mean-field Gross-Pitaevskii approximation for the propagating Bose-Einstein condensate, we show that the presence of a weak atom-atom interaction within the ring leads to an inversion of the AAS oscillations, in a very similar manner as for the coherent backscattering of Bose-Einstein condensates within two-dimensional disorder potentials [2]. Truncated Wigner simulations reveal that this signature of weak antilocalization becomes washed out if the interaction strength is increased, which is in qualitative agreement with the findings of the diagrammatic study undertaken in Ref. [3].

[1] B. L. Al'tshuler, et. al., JETP Lett. 33, 94 (1981).

[2] M. Hartung, et. al., PRL. 101, 020603 (2008).

[3] T. Geiger, et. al., New J. Phys. 15, 115015 (2013).

Q 50.6 Wed 15:15 K 2.020

A noiseless matter wave readout amplifier for atom interferometry — •Daniel Linnemann, Philipp Kunkel, Helmut Strobel, Maximilian Prüfer, Stefan Lannig, Rodrigo Rosa-Medina Pimentel, Martin Gärttner, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, Heidelberg

We present a quantum-enhanced atom interferometer whose output state is magnified by a noiseless readout amplifier for matter waves. In presence of spurious technical detection noise, subsequently amplifying the interferometer's output can improve the overall sensitivity.

The amplification process which usually degrades the signal-to-noise ratio by at least three decibels, is rendered noiseless in our scheme by entangling the amplifier with its input. In this way, non-classical correlations are leveraged in two respects: they enhance the interferometer's phase sensitivity and facilitate the readout.

Experimentally, we employ spin exchange in a Bose-Einstein condensate as the underlying entangling interaction. This scattering process among spins can be understood as parametric amplification. We detail the noise characteristics when using spin exchange as a phase-preserving linear amplifier. Attaching the amplification stage to an interferometer, we explicitly demonstrate that quantum-enhanced phase sensitivity is maintained even for large magnifications of the signal.

Q 50.7 Wed 15:30 K 2.020

Beating the classical precision limit with spin-1 Dicke state — Yi-Quan Zou, •Ling-Na Wu, Qi Liu, Xin-Yu Luo, Shuai-Feng Guo, Jia-Hao Cao, Meng Khoon Tey, and Li You — State Key Laboratory of Low Dimensional Quantum Physics, Department of Physics, Tsinghua University, Beijing 100084, China

Entanglement plays an important role in quantum information and precision measurement. The generation of entangled states thus constitutes a research frontier and tremendous progresses along this direction have been made during the past decade. Among the variety of entangled states, Dicke states form an important class. Most of the Dicke states produced to date are limited to pseudo-spin-1/2 (two-level) particles. Here, we report the first generation of a balanced spin-1 Dicke state in a Bose Einstein condensate. We also demonstrate its application in precision measurement by performing a precise rotation angle measurement with the generated state as input, which leads to a measurement sensitivity beyond the classical limit.

Q 50.8 Wed 15:45 K 2.020

Emergence of striped states in quantum ferrofluids — •Antun Balaž[1] and Axel Pelster[2] — [1]Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Germany

In the recent experiment [1], striped states in a many-body system of tilted dipoles were observed in a quantum ferrofluid of a strongly dipolar BEC of dysprosium, leading to a formation of atomic droplets. In Ref. [2] it was demonstrated that the stability of such droplets is due to a quantum fluctuation correction of the ground-state energy [3, 4]. Here we extend this previous theoretical description and develop a full Bogoliubov-Popov theory, which also takes into account the condensate depletion due to quantum fluctuations. We apply our novel approach to study in detail the emergence of striped states and their properties. To this end we perform extensive numerical simulations and determine how the critical tilting angle depends on both the atom number and the trap geometry. Our investigations turn out to be relevant for extracting the yet unknown s-wave background scattering length of dysprosium from the experiments of Ref. [1].

[1] M. Wenzel, et al., arXiv:1706.09388 (2017).
[2] L. Chomaz, et al., Phys. Rev. X **6**, 041039 (2016).
[3] T. D. Lee, et al., Phys. Rev. **106**, 1135 (1957).
[4] A. R. P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011); Phys. Rev. A **86**, 063609 (2012).

Q 51: Poster: Quantum Optics and Photonics IV

Time: Wednesday 16:15–18:15 Location: Redoutensaal

Q 51.1 Wed 16:15 Redoutensaal

Observation of parametric instabilities in 1D interacting shaken optical lattice systems — •Karen Wintersperger[1,2], Jakob Näger[1,2], Marin Bukov[3], Martin Reitter[1,2], Samuel Lellouch[4], Ulrich Schneider[5], Nathan Goldman[4], Immanuel Bloch[1,2], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstr. 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching — [3]Boston University, 590 Commonwealth Ave., Boston, MA 02215 — [4]Université Libre de Bruxelles, CP 231, Campus Plaine, 1050 Brussels, Belgium — [5]University of Cambridge, Cambridge, UK

We study the dynamics of BECs in a driven optical 1D lattice using 39K atoms that have an accessible Feshbach resonance allowing for the control of interactions. The short-time dynamics is mostly dominated by parametric instabilities [1] and can be well described within Bogoliubov theory. At longer times this description seizes to be accurate and the dynamics can be captured by a Fermi*s golden rule approach [2]. We observe the transition between the two regimes for different shaking parameters and interactions. Also, we compare the quasimomentum of the most unstable modes to the values expected from Bogoliubov theory.

[1] S. Lellouch et al., PRX 7, 021015, 2017
[2] M. Reitter et al., PRL 119, 200402, 2017

Q 51.2 Wed 16:15 Redoutensaal

Nonlinear standing waves in an array of coherently coupled 1D Bose-Einstein condensates — •Christian Baals[1,2], Antonio Muñoz Mateo[3], Herwig Ott[1], and Joachim Brand[3] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Germany — [3]Dodd-Walls Centre for Photonics and Quantum Technologies, Centre for Theoretical Chemistry and Physics, New Zealand Institute for Advanced Study, Massey University, Auckland, New Zealand

We study the stability of dark soliton states in an array of linearly coupled 1D BECs within the Gross-Pitaevskii theory against linear excitations by solving the Bogoliubov equations. In this context we show that overlapped dark solitons can decay into patterns of Josephson vortices over the stack of Josephson junctions. By analytically solving the Bogoliubov equations for dark solitons, the Josephson vortices are demonstrated to bifurcate as nonlinear standing waves for decreasing values of the linear coupling. This result is very well confirmed by numerical studies. Furthermore, we discuss the connection with the stability of dark solitons in two dimensional systems and consider the feasibility for an experimental realisation.

Q 51.3 Wed 16:15 Redoutensaal

A quantum gas machine for local photoionization of ultracold ^{87}Rb on ultrafast time-scales — •Jakob Butlewski[1], Tobias Kroker[1,2], Bernhard Ruff[1,2], Juliette Simonet[1,2], Philipp Wessels[1,2], Markus Drescher[1,2], and Klaus Sengstock[1,2] — [1]Zentrum für Optische Quantentechnologien (ZOQ), Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg, Germany

Combining ultracold atoms with ultrashort laser pulses offers novel experimental possibilities such as the creation of hybrid quantum systems by local ionization of atoms in strong laser fields or the investigation of quantum Zeno physics with pulsed dissipation.

Here, we report on our progress in setting up an experiment for local photoionization in quantum gases and the detection of thereby created charged particles. The ultracold atomic sample is prepared in a combined magnetic quadrupole and optical dipole trap and is transported into the focal region of the ionizing femtosecond laser beam using optical tweezers. Subsequently, the emerging photoelectrons shall be detected with spatial resolution while counting the ions in coincidence. In order to obtain unperturbed trajectories of the charged particles electrical stray fields are shielded and an active magnetic field compensation has been set up.

Q 51.4 Wed 16:15 Redoutensaal

Non-equilibrium dynamics of interacting Bosons in an optical lattice — •Johannes Bauer[1], René Hamburger[1], Jens Benary[1], Christian Baals[1,2], Jian Jiang[1], Andreas Müllers[1], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, 55128 Mainz, Germany

We study the non-equilibrium dynamics of ultracold Bose gases in optical lattices using a scanning electron microscope. In a first experiment we characterize the emerging steady-states of a driven-dissipative Josephson junction array, realized with a BEC in a one-dimensional optical lattice. By locally applying dissipation using the electron beam at an initially full site, we can induce a superfluid response which keeps the respective site filled. This can be seen as an extension of the paradigm of Coherent Perfect Absorption (CPA). CPA refers to the complete extinction of incoming radiation by spatially localized absorber embedded in a wave-guiding medium. Furthermore, we make use of the Talbot effect to study phase coherence in an optical lattice at a finite range. The interferometer which relies on the fast blanking of the lattice potential is applied to study the spread of phase coherence after a quench of the lattice depth. Our current work is focused on the generation and stabilization of dark solitons in 3D. To imprint the phase step of π onto a BEC we use a Digital Micromirror Device to create a sharp edge in the beam profile of a 532nm laser. We will then make use of the electron beam as a source of local dissipation to stabilise the dark soliton.

Q 51.5 Wed 16:15 Redoutensaal

Bloch oscillations in the second band of an optical lattice — •Carl Hippler, José Vargas, Thorge Kock, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

The overall goal of our experiment is to explore ultracold bosonic quantum gases in excited bands of an optical lattice. We investigate Rb-87 atoms in a bipartite interferometric 2D lattice allowing us to change the lattice geometry dynamically. We observe the formation of a chiral superfluid order, arising from the interplay between the contact interaction of the atoms on each lattice site and the degeneracy of the p orbitals in the second Bloch band. A periodic pattern of locally alternating orbital currents and circular currents establishes in the lattice, time-reversal symmetry being spontaneously broken. We report on Bloch oscillations in the second band of the lattice, starting at the two inequivalent X points.

Q 51.6 Wed 16:15 Redoutensaal

Non-equilibrium dynamics in a quasi-1D spinor BEC: demonstration and new probing tools — •Stefan Lannig, Rodrigo Rosa-Medina Pimentel, Maximilian Prüfer, Philipp Kunkel, Christian-Marcel Schmied, Daniel Linnemann, Helmut Strobel, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg

We employ a spinor Bose-Einstein condensate of ^{87}Rb confined in an elongated dipole trap to study far from equilibrium dynamics with spin exchange interactions. In order to investigate the underlying dynamics we prepare the system in the polar phase and quench into the easy-plane ferromagnetic phase. After an exponential build-up of excitations we identify the emergence of a universal scaling function for intermediate times. By rescaling the power spectra of the transversal spin auto-correlations we extract the corresponding scaling exponents, thereby observing self-similar evolution in time.

We further present an extension of our experimental toolbox for performing local spin rotations. Using acousto-optical deflectors the atomic cloud is addressed by a steerable laser beam. The resulting AC vector Stark shift influences the energies of the individual Zeeman spin components similar to an applied magnetic bias field. Modulating the light intensity at the Larmor frequency enables the implementation of spatially resolved spin rotations. This allows us to explore different initial configurations, and we envision schemes to probe time-time correlations.

Q 51.7 Wed 16:15 Redoutensaal

An experimental setup for the study of universality far from equilibrium with degenerate ^{39}K — •Maurus Hans, Celia Viermann, Alexander Impertro, Marius Sparn, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Deutschland

In thermal equilibrium different physical systems close to a phase transition are described by the same set of critical exponents given by the corresponding universality class. This concept can be extended to non-equilibrium dynamics where theoretical studies show that universal scaling in time and space appear also away from an equilibrium critical point [1]. In degenerate quantum gases, universality can be reached by a quench close to such a critical point [2], but also by just abruptly changing the scattering length such that the system is driven out of equilibrium [3,4]. For this purpose, a ^{39}K Bose-Einstein condensate is an especially promising experimental system since it exhibits a broad magnetic Feshbach resonance for interaction tuning. Here, we present the status of the current experimental setup and schemes for the detection of universal time dynamics.

[1] B. Nowak et al., in Strongly Interacting Quantum Systems out of Equilibrium, ed. T. Giamarchi et al., Lecture Notes of the Les Houches Summer School Vol. 99, 2016 [2] E. Nicklas et al., Phys. Rev. Lett. 115, 245301 (2015) [3] J. Berges et. al., Phys. Rev. Lett. 114, 061601 (2015) [4] B. Nowak et al., Phys. Rev. B 84, 020506(R) (2011)

Q 51.8 Wed 16:15 Redoutensaal

Creating a superfluid by kinetically driving a Mott insulator — •Gregor Pieplow, Charles E. Creffield, and Fernando Sols — Departamento de Física de Materiales, Universidad Complutense de Madrid, E-28040 Madrid, Spain

We study the effect of time-periodically varying the hopping amplitude (which we term "kinetic driving") in a one-dimensional Bose-Hubbard model, such that the time-averaged hopping is zero. By using Floquet analysis we derive a static effective Hamiltonian in which nearest-neighbor single-particle hopping processes are suppressed, but all even higher-order processes are allowed. Unusual many-body features arise from the combined effect of nonlocal interactions and correlated tunneling. At a critical value of the driving, the system passes from a Mott insulator to a superfluid formed by two quasi-condensates with opposite nonzero momenta. A many-body cat state combining the two macroscopically-occupied momentum eigenstates emerges even with hard-wall boundary conditions. We also explore Bogoliubov-de Gennes theory, which allows to infer the nature of the excitations of the fragmented superfluid. This work shows how driving of the hopping energy provides a novel form of Floquet engineering, which enables atypical Hamiltonians and exotic states of matter to be produced and controlled.

Q 51.9 Wed 16:15 Redoutensaal

Dynamics of Vector Solitons in Spinor Bose-Einstein Condensates — •Kevin Geier[1], Sebastian Erne[1,2,3], Christian-Marcel Schmied[1], Markus K. Oberthaler[1], and Thomas Gasenzer[1] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]VCQ, Atominstitut, TU Wien, Stadionallee 2, 1020 Wien, Austria

We study the role of topological excitations in the non-equilibrium dynamics of a spin-1 Bose-Einstein condensate in one spatial dimension. In absence of the Zeeman effect and spin-spin interactions, the equations of motion reduce to the completely integrable Manakov system, which supports exact vector soliton solutions of dark-bright type. Integrability imposes strong constraints on the system's dynamics, such that, in essence, solitons always scatter elastically. Tuning the couplings to different mean-field phases, we study the effects of integrability breaking on the solitons' dynamics by numerically solving the full spin-1 Gross-Pitaevskii equations. Our results reveal non-trivial interaction effects such as inelastic scattering and the decay of solitons into domain walls. We furthermore study the time evolution of correlation functions for a random distribution of solitons in the easy-plane phase in comparison to a system initially prepared in the polar ground state. We find that the system approaches power-law distributions in momentum space reflecting the self-similar coarsening dynamics induced by dynamical instabilities.

Q 51.10 Wed 16:15 Redoutensaal

Floquet engineering in periodically driven optical lattices — •Alexander Ilin, Tobias Klafka, Julius Seeger, Mario Neundorf, Christoph Ölschläger, Juliette Simonet, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Time-periodic forcing is a powerful technique to explore new exciting phenomena in quantum many-body systems, e.g. artificial magnetism or topological phases of matter. For atoms in optical lattices it allows engineering of exotic band structures where coupling to higher Bloch bands can have severe effects even at moderate shaking amplitudes and off-resonant driving.

Here, we focus on band structure engineering for a BEC in a 1D optical lattice subject to monochromatic shaking near band inversion by varying the shaking strength across the point where the effective nearest neighbour tunneling parameter t_{NN} has a zero-crossing. The point of band inversion, characterizing the transition in the occupation of states from zero quasi-momentum to the Brillouin zone edge, has been recorded systematically as a function of lattice depth and shaking frequency. Our measurements reveal a striking dependence upon these variables which can be explained by admixtures of higher Bloch bands.

Q 51.11 Wed 16:15 Redoutensaal

In situ observation of Bloch oscillations in an optical cavity — •Christoph Georges[1], Jens Klinder[1], Hans Kessler[1,2], and Andreas Hemmerich[1,3] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Instituto de Física de São Carlos, Universidade de São Paulo — [3]Wilczek Quantum Center, Zhejiang University of Technology

Observing the Bloch oscillations of an ultracold quantum gas in an optical lattice is a promising approach to measure weak forces with high precision. The creation time of these ultracold quantum gas in combination with the common detection via Time-of-Flight imaging inherit a bad data acquisition speed.

In our Recent work [1] we have shown experimentally, the direct observation of Bloch oscillation of a strong cooperative coupled BEC inside an optical cavity via the light leaking out of this cavity. And in this way, we accelerated the acquisition speed for the Bloch-frequency substantially.

Here we report on our newest results on open questions concerning this detection scheme. Among others, we investigated the question if our coupling scheme changes the Bloch-frequency.

[1] H Keßler et al 2016 New J. Phys. 18 102001

Q 51.12 Wed 16:15 Redoutensaal

Dissipation-induced steady states in Rydberg-dressed quantum gases in an optical lattice — •Mathieu Barbier, Andreas Geissler, and Walter Hofstetter — Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität Frankfurt am Main

In recent years, research on quantum gases trapped in optical lattices has flourished impressively and the addition of Rydberg excitations to such systems promises to lead to exotic phases. Alongside the insulating density waves with crystalline order and superfluids, intriguing quantum phases referred to as supersolids have been predicted. Those phases are characterized by a spatially modulated condensate, combining the long-range spatial order of solids and the superfluid flow of condensates.

We focus on the realization of various quantum phases of a bosonic Rydberg-dressed gas, trapped in an optical lattice. Using the master equation in Lindblad form within the Gutzwiller theory and its approximations, we enrich the system with realistic dissipative mechanisms in order to closely model the experiment. We let the non-dissipative ground states evolve and observe the influence of dissipation. Are stable supersolids attainable in experiments or do dissipative processes prevent their existence?

Q 51.13 Wed 16:15 Redoutensaal

Observation of a pure Goldstone mode in the quench dynamics of an ultracold BCS Fermi gas — •Peter Kettmann[1], Simon Hannibal[1], Mihail Croitoru[2], Vollrath Martin Axt[2], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster — [2]Theoretical Physics III, University of Bayreuth

Ultracold Fermi gases are a convenient system to probe and study the properties of phases like the BEC and the BCS phase and the crossover in between those regimes. In particular, ultracold Fermi gases can be used as a test bed to study the two fundamental dynamical modes –the Higgs and the Goldstone mode– which result from spontaneous symmetry breaking in these phases.

We investigate the Goldstone mode in the dynamics of a cigar-shaped cloud of ultracold ^{6}Li after a moderate interaction quench on the BCS side of the BCS-BEC crossover. To this end, we numerically solve Heisenberg's equations of motion for the Bogoliubov single-particle excitations in the framework of the Bogoliubov-de Gennes formalism. We observe that the quench leads to the emergence of a homogeneous Goldstone mode which does not couple to the trap and which is –as a result– gapless. In contrast to previous studies, we therefore observe the emergence of a pure Goldstone mode, i.e., a Goldstone mode in the original sense of the Goldstone theorem.

Furthermore, we investigate several ways to experimentally access the pure Goldstone mode, i.e., via a collective motion of the condensate, via its single-particle excitations, and via an interference setup.

Q 51.14 Wed 16:15 Redoutensaal

Persistent oscillations in the Higgs mode in a cigar-shaped ultracold Fermi gas — •Simon Hannibal[1], Peter Kettmann[1], Mihail Croitoru[2], Vollrath Martin Axt[2], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster — [2]Theoretical Physics III, University of Bayreuth

Ultracold Fermi gases in optical traps provide a unique system to study the many body physics of systems composed of fermionic constituents. Both, the BEC and the BCS superfluid state are observed. Furthermore, the transition between these states is well controllable by means of a Feshbach resonance, which allows to tune the scattering length over a wide range from negative to positive values.

We employ an inhomogeneous BCS mean field theory and calculate the dynamics of the BCS gap of a confined ultracold Fermi gas after an interaction quench. Due to the spontaneously broken U(1) symmetry in the superfluid phase two fundamental modes of the BCS gap evolve, i.e., the amplitude (Higgs) and phase (Goldstone) mode. Here, we focus on the Higgs mode on the BCS side of the BCS-BEC crossover.

We investigate the dynamics resulting from interaction quenches starting deep in the BCS regime and ending in the BCS-BEC crossover region. We find a nonlinear persistent dynamics with one dominant frequency. For all quenches, this frequency stays closely connected to the long time average of the modulus of the BCS gap. We show that both are determined by a breaking of Cooper pairs at the time of the quench. Furthermore, we find that our model exhibits a chaotic behavior for large quenches ending in the BCS-BEC crossover region.

Q 51.15 Wed 16:15 Redoutensaal

Local control of transport in an atomic quantum wire — •Philipp Fabritius[1], Samuel Häusler[1], Martin Lebrat[1], Dominik Husmann[1], Laura Corman[1], Jean-Philippe Brantut[2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland — [2]Institute of Physics, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

We demonstrate the local control of fermionic lithium atoms flowing through a one-dimensional structure by imprinting holographically shaped optical potentials with a high-resolution microscope. Similar to the scanning gate technique applied to solid-state devices we image the transport through a quantum wire at the scale of the Fermi wavelength by scanning the position of a sharp, repulsive optical gate. Imprinting complex structures such as a lattice enables us to study the metal-insulator transition in an interacting one-dimensional Fermi gas. We find that the insulating state is robust even for strong attractive interactions, which supports the existence of a Luther-Emery liquid in the one-dimensional wire.

The flexibility of our setup makes it possible to project additional structures onto a wire or a quantum point contact. In particular close-to-resonance light can be used to implement dissipative lattices or a spin valve.

Q 51.16 Wed 16:15 Redoutensaal

Exploring the Single-Particle and Many-Body Mobility Edge in a 1D Quasiperiodic Optical Lattice — •Thomas Kohlert[1,2], Sebastian Scherg[1,2], Henrik Lüschen[1,2], Michael Schreiber[1,2], Pranjal Bordia[1,2], Monika Aidelsburger[1,2], Xiao Li[3], Sankar Das Sarma[3], and Immanuel Bloch[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstr. 4, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [3]Condensed Matter Theory Center and Joint Quantum Institute, University of Maryland, College Park, Maryland 20742-4111, USA

A single-particle mobility edge (SPME) marks a critical energy separating extended from localized states in a quantum system. In this work, we find experimental evidence for the existence of such a SPME in a one-dimensional quasi-periodic optical lattice. Specifically, we find a regime where extended and localized single-particle states coexist, in good agreement with theoretical simulations, which predict a SPME in this regime. In the corresponding interacting system we find that the dynamics is continuously slowing down as we approach a critical disorder strength, indicating that the system shows many-body localization (MBL). We juxtapose two models with and without SPME and compare their dynamics on short and long timescales and find that the interacting system does not delocalize on short timescales despite the presence of single-particle extended states. Finally, we discuss whether a many-body mobility edge (MBME) might be present in our system.

Q 51.17 Wed 16:15 Redoutensaal

Many-body phases of fermions coupled to an optical waveguide — •Kieran Fraser and Francesco Piazza — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Ultracold atoms subject to a single cavity mode will, above a threshold pump strength, undergo a self-organisation transition, related to so-called superradiance. A similar effect is observed for atoms in the evanescent field of an optical fibre. We study the phase diagram and collective excitations of a degenerate Fermi gas coupled to the propagating modes of a multimode optical waveguide. The interplay between superradiant and Umklapp scattering gives rise to a rich phase diagram and to peculiar collective excitations.

Q 51.18 Wed 16:15 Redoutensaal

Experimental investigation of Floquet dynamics in the driven Fermi-Hubbard model — •Frederik Görg[1], Michael Messer[1], Kilian Sandholzer[1], Joaquín Minguzzi[1], Gregor Jotzu[1,2], Rémi Desbuquois[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany

Driving a many-body system allows to engineer new Hamiltonians and realize interesting phases which are beyond the reach of static platforms. One example is the near-resonantly driven Fermi-Hubbard model, where the modulation frequency is chosen to be close to the interaction energy. To lowest order, the system is described by an effective Hamiltonian in which the single particle tunnelling and the magnetic exchange energies can be controlled independently. When going beyond this approximation, the underlying many-body state shows interesting dynamics on different timescales: Starting from fast micromotion during a single modulation period, the system is entering a regime described by the effective Hamiltonian on intermediate timescales before eventually heating up due to energy exchange with the drive. The experimental implementation of this model allows us to investigate all these timescales and observe the built-up and destruction of double occupancies and spin-spin correlations. In addition, we investigate the adiabaticity of the preparation protocol starting from a thermal state in the static lattice. We compare our results to theoretical predictions for the driven Fermi-Hubbard model.

Q 51.19 Wed 16:15 Redoutensaal

Towards Quantum Simulation of the Kondo Lattice Model — •Benjamin Abeln[1], Marcel Diem[1], Koen Sponselee[1], Maximilian Hagenah[1], Bodhaditya Santra[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Over the last decade ultracold fermionic alkaline earth quantum gasses attracted a lot of attention due to their unique properties such as an ultra-narrow optical clock transition, a long-lived meta-stable state, SU($\mathcal{N}$) symmetric interactions, and the existence of an interorbital Feshbach resonance. In particular, fermionic ytterbium (Yb) quantum gases loaded into a state-dependent optical lattice allow for quantum simulation of lattice systems with orbital degrees of freedom, like the Kugel-Khomskii model or the Kondo lattice model (KLM). In the state-dependent lattice, the ground state atoms mimic the mobile spins in the KLM, whereas the excited state atoms represent the localized spin impurities.

We present progress towards the quantum simulation of the KLM with fermionic Yb atoms, including the loading of ground state atoms into a state-dependent lattice and the necessary refinements to the optical clock setup for flexible initial state preparation.

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

Q 51.20 Wed 16:15 Redoutensaal

Manipulating spin correlations in a periodically driven many-body system — •Kilian Sandholzer[1], Frederik Görg[1], Michael Messer[1], Joaquìn Minguzzi[1], Gregor Jotzu[1,2], Rémi Desbuquois[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany

Periodic driving can be used to coherently control the properties of a many-body state and to realize new phases which are not accessible in static systems. In this context, cold fermions in optical lattices provide a highly tunable platform to investigate driven many-body systems and additionally offer the prospect of quantitative comparisons to theoretical predictions. We implement a driven Fermi-Hubbard model by periodically modulating a 3D hexagonal lattice. In the regime where the drive frequency is much higher than all other relevant energy scales, we verify that the interacting system can be described by a renormalized tunneling. Furthermore, we achieve independent control over the single particle tunneling and the magnetic exchange energy by driving near-resonantly to the interaction. As a consequence, we are able to show that anti-ferromagnetic correlations in a fermionic many-body system can be enhanced or even switched to ferromagnetic correlations. The implementation of more complex modulation schemes opens the possibility to combine the physics of artificial gauge fields and strongly-correlated systems.

Q 51.21 Wed 16:15 Redoutensaal

High temperature pairing in a strongly interacting two-dimensional Fermi gas — •Marvin Holten, Puneet Murthy, Luca Bayha, Ralf Klemt, Gerhard Zürn, Philipp Preiss, and Selim Jochim — Physikalisches Institut, University of Heidelberg, Germany

On this poster we present our observation of many-body pairing in a two-dimensional gas of ultracold fermionic atoms at temperatures far above the critical temperature for superfluidity. We use spatially resolved radio-frequency spectroscopy to measure pairing energies spanning a wide range of temperatures and interaction strengths. In the strongly interacting regime, where the scattering length between fermions is on the same order as the inter-particle spacing, the pairing energy in the normal phase significantly exceeds the intrinsic two-body binding energy of the system and shows a clear dependence on local density. This implies, that pairing in this regime is driven by many-body correlations rather than two-body physics. We find this effect to persist at temperatures close to the Fermi temperature, which demonstrates that pairing correlations in strongly interacting two-dimensional fermionic systems are remarkably robust against thermal fluctuations. In addition, we present our study of collective excitation modes of our fermionic atom cloud in its two-dimensional harmonic confinement. Our current results support the observation of a quantum anomaly due to interactions breaking the scale invariance of the two-dimensional gas.

Q 51.22 Wed 16:15 Redoutensaal

Bridging the thermoelectric and superfluid fountain effects with ultracold fermions — •Martin Lebrat, Dominik Husmann, Samuel Häusler, Philipp Fabritius, Laura Corman, Jean-Philippe Brantut, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zürich, Switzerland

An out-of-equilibrium system with temperature and chemical potential gradients needs both heat and matter currents to relax to thermodynamical equilibrium. The relaxation dynamics illuminates the microscopic mechanisms responsible for transport and energy conversion between heat and work, which is of great technological importance for cooling (Peltier effect) or power generation (Seebeck effect).

Using two reservoirs of fermionic lithium-6 atoms connected by an optically-shaped constriction, we demonstrate such thermoelectric effects and investigate the influence of interactions and constriction properties. With weak interactions and a 2D constriction, thermoelectric coupling can be optimized by controlling the geometry or introducing disorder [1]. With strongly interacting fermions close to the superfluid transition and a quasi-1D constriction, the system evolves towards a non-equilibrium steady state, associated with a reduced heat diffusion and a strong violation of the Wiedemann-Franz law. Measuring thermoelectric transport coefficients as a function of constriction anisotropy and degeneracy, we underline the analogies and differences between our observations and the celebrated fountain effect shown with superfluid helium-4.

[1] J.-P. Brantut et al., Science **342**, 713 (2013)

Q 51.23 Wed 16:15 Redoutensaal

Fast, long-distance transport of single atoms using quantum optimal control — •Thorsten Groh[1], Manolo Rivera[1], Natalie Thau[1], Max Werninghaus[1], Carsten Robens[1], Wolfgang Alt[1], Dieter Meschede[1], Antonio Negretti[2], and Andrea Alberti[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany

We present a digital phase and amplitude control loop setup based on a field programmable gate array (FPGA) which enables fast transport of single cesium atoms in polarization-synthesized optical lattices over macroscopic distances. Using analog control techniques, we could demonstrate fast atom transport over single lattice sites with minimal motional excitations and transport times down to the quantum speed limit. This is achieved by modulating both position and depth of the optical lattice potential by means of quantum optimal control theory. The new FPGA-based control system allows us to implement internal model control schemes enabling feed-forward driving. This dramatically extends the bandwidth of the feedback from 1 MHz to about 10 MHz. This not only allows single-site transport of atoms in less than the oscillation period of the trapping potential, but also provides an ideal platform for long distance and multiple step transport sequences. Fast atom transport over macroscopic distances will enable high precision atom interferometry and quantum information applications.

Q 51.24 Wed 16:15 Redoutensaal

Designing two-dimensional dynamical potentials using fast controllable devices — •Mareike Hetzel, Andreas Hüper, Cebrail Pür, Jiao Geng, Ilka Kruse, Jan Peise, and Carsten Klempt — Institut für Quantenoptik, Leibniz Universität Hannover

Arrays of atoms trapped by optical tweezers enable the study of phenomena in the field of quantum computing and many-body physics. The individual control of each site allows the precise quantum engineering of freely adjustable Hamiltonians. Here, we present the generation of arbitrary two-dimensional light patterns with fast dynamic control. The patterns are created by an acousto-optic deflector together with a versatile software-based radio-frequency generator. Our solution offers higher dynamic modulation speeds compared to competing system with digital micromirror devices or spatial light modulators. We present a test setup that is used to characterize the key components and demonstrate its capabilities by generating a set of optical potentials including lattice patterns, defects and dynamically generated structures. We further show a possible implementation of the setup in our experimental apparatus.

Q 51.25 Wed 16:15 Redoutensaal

Optical trapping of ion Coulomb crystals — •Julian Schmidt, Yannick Minet, Pascal Weckesser, Fabian Thielemann, Markus Debatin, Leon Karpa, and Tobias Schaetz — Physikalisches Institut, Universität Freiburg, Deutschland

Ion Coulomb crystals are the key to many applications with trapped ions, as the crystal phonons mediate interaction between ions and allow coupling of electronic and motional states on the quantum level [1]. However, rf-micromotion in ion traps poses fundamental limits for applications with higher-dimensional Coulomb crystals [2] and in ultracold chemistry experiments. Optical dipole traps for trapped ions [3] do not exhibit this micromotion, but only trapping of single ions had been demonstrated thus far.

We now demonstrate trapping of ion crystals consisting of up to six

Barium ions in an optical dipole trap aligned with the crystal axis without confinement by radio-frequency (RF) fields. The dependence on the trap parameters, in particular the interplay of beam waist, laser power and axial confinement by DC electric fields, is investigated. As a proof-of-principle experiment, we detect the center-of-mass and stretch modes for an optically trapped two-ion crystal. Finally, we present prospects for optical trapping of higher-dimensional Coulomb crystals.

[1] D.J. Wineland, Rev. Mod. Phys. 85, 1103 (2013)
[2] R. Thompson, Contemp. Phys. 1,56, 63-79 (2015)
[3] A. Lambrecht et al., Nat. Phot. 11, 704-707 (2017)

Q 51.26 Wed 16:15 Redoutensaal

Laser cooling of dysprosium — •Niels Petersen[1,2], Florian Mühlbauer[1], Lena Maske[1], Carina Baumgärtner[1], and Patrick Windpassinger[1,2] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany

Ultra-cold dipolar quantum gases enable the study of many-body physics with long-range, inhomogeneous interaction effects due to the anisotropic character of the dipole-dipole interaction. These systems are expected to show novel exotic quantum phases and phase transitions which can be studied with dysprosium atoms. Dysprosium is a rare-earth element with one of the largest ground-state magnetic moments (10 Bohr magnetons) in the periodic table. Therefore, the dipole-dipole interaction is not a small perturbation but becomes comparable in strength to the s-wave scattering. This influences significantly the physical properties of the trapped atomic sample, such as its shape and stability. This poster presents the current status of our experimental setup to generate dysprosium quantum gases. We present our results in laser cooling of dysprosium atoms and give an overview of our laser system and vacuum design.

Q 51.27 Wed 16:15 Redoutensaal

Setup of a new micro-structured linear Paul trap with integrated electro magnets and reduced axial micromotion — •Hendrik Siebeneich, Timm F. Gloger, Peter Kaufmann, Michael Johanning, and Christof Wunderlich — Department Physik, Universität Siegen, 57068 Siegen, Germany

We present the experimental status of a new 3d segmented ion trap setup with integrated electro magnets. Here, an improved design allows for a substantial reduction of axial micromotion and for an increased magnetic gradient necessary for radio frequency-driven conditional quantum dynamics. The trap consists of three layers of gold plated alumina, where the segmented outer layers provide the trapping potentials [1]. The newly designed middle layer contains micro-structured electro magnets that create a spatially inhomogeneous magnetic field. This gradient field gives rise to coupling between internal and motional states of trapped ions. The trap is mounted on a ceramic chip carrier that, at the same time, acts as an ultra-high vacuum interface, featuring about 100 thick-film printed current and voltage feedthroughs. The RF- and DC-electrodes of the segmented trap as well as Ytterbium ovens and electro magnets are connected to the vacuum interface via printed circuit boards. The contact between the thick-film printed wires and the boards is made by a silk-screen printed solder that melts at a low temperature of 150°C.

[1] D. Kaufmann et al.: Thick-film technology for ultra high vacuum interfaces of micro-structured traps, Appl. Phys. B **107**, 935 (2012).

Q 51.28 Wed 16:15 Redoutensaal

Next generation atom chip development — •Alexandros Papakonstantinou[1], Hendrik Heine[1], Melanie Le Gonidec[1], Alexander Kassner[2], Mathias Rechel[2], Waldemar Herr[1], Marc C. Wurz[2], Wolfgang Ertmer[1], and Ernst M. Rasel[1] — [1]IQ, Leibniz Universität Hannover — [2]IMPT, Leibniz Universität Hannover

Despite the additional efforts imposed by their production, atom chips are an interesting source for Bose-Einstein condensates (BECs) since they are versatile, robust and also fast in the creation of a BEC. New applications in sensing and interferometry even live on further, expanding the functionalities on reduced outgassing and optical functionality.

On this poster we will present the recent developments of our atom chips featuring non-adhesive conjunction techniques, advanced materials and the combination of atom chips with optical gratings. This will lead to simplification and compactification of the overall setup enabling compact quantum sensors in the future. Furthermore we will show our new experiment, which is optimized for fast testing of atom chips.

This work is supported by the Deutsche Forschungsgemeinschaft (DFG) in the scope of the SFB 1128 geo-Q and by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant number DLR 50WM1650 (KACTUS).

Q 51.29 Wed 16:15 Redoutensaal

Characterization of a source of slow metastable Kr atoms — •Ergin Simsek, Markus Kohler, Carsten Sieveke, Pablo Woelk, Christoph Becker, and Klaus Sengstock — Universität Hamburg, Deutschland

Kr^{85} is produced only anthropogenically by nuclear fission. Therefore its concentration in the atmosphere has increased since the beginning of the nuclear age. With its half life of 10.76 years, Kr^{85} can be used as a tracer for measuring the regeneration cycles of young ground waters.

For this application we are developing a measurement chain including sampling, sample preparation and an isotope-selective concentration measurement. For the determination of Kr^{85} content our setup is based on the Atom Trap Trace Analysis (ATTA) method which is sensitive to the parts-per-trillion level.

The measurement device uses a 2D-3D magneto-optical trap (MOT), capable of capturing and counting specific isotopes down to the single atom regime. As it is not possible to cool and trap Kr from the ground state, we first prepare the atoms to a metastable state.

To avoid cross contamination we implement an all-optical excitation scheme which includes an in-house developed VUV lamp emitting 123 nm and a 819 nm diode laser system. Because of the complex relationship between excitation and capturing dynamics within the 2D MOT we evaluate spatial distribution of the excitation by measuring the loading rate of the 3D MOT.

Q 51.30 Wed 16:15 Redoutensaal

Gauge fields and topological states with ultracold erbium atoms — •Roberto Vittorio Röll, Daniel Babik, Carl Cheung, Jens Ulitzsch, and Martin Weitz — Institut für Angwandte Physik, Universität Bonn

We report on progress in an ongoing experiment directed at the observation of topological states of ultracold erbium atoms in a synthetic magnetic gauge field.

In alkali atoms with their S-ground state configuration in far detuned laser fields with detuning above the upper state fine structure splitting the trapping potential is determined by the scalar electronic polarizability. In contrast, for an atomic erbium quantum gas with its $L > 0$ electronic ground state, the trapping potential for inner-shell transitions also for far detuned dissipation-less trapping laser fields becomes dependent on the internal atomic state (i.e. spin). Therefore it is expected to reach much longer coherence times with atomic erbium in spin-dependent optical lattice experiments and for far detuned Raman manipulation in comparison with the usual alkali atoms.

In our Bonn experiment an atomic erbium Bose-Einstein condensate (BEC) is generated in a quasistatic optical dipole trap provided by a focused mid-infrared CO_2-laser beam. In the next experimental step, we plan to realize synthetic magnetic fields by phase imprinting with Raman manipulation beams. The goal is to observe fractional quantum Hall physics for atoms in a strong synthetic magnetic field.

Q 51.31 Wed 16:15 Redoutensaal

Satellite-based links for Quantum Key Distribution: a comprehensive model — •Carlo Liorni, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität, Institut für Theoretische Physik III, Düsseldorf, Germany

Quantum Key Distribution has the potential to become the first quantum technology to be applied in a real-world scenario. For intercontinental distances, the intrinsic losses introduced by silica fibres become too detrimental to establish any kind of useful communication. Satellite-based quantum links could, in principle, allow to cover such long distances. Uplinks and downlinks, comprising either a sending or a receiving ground station, are subjected to the deleterious effects of turbulent atmosphere and bad weather conditions.

We start from the model proposed in [1], in order to analyse the propagation of quantum light in a turbulent atmosphere with additional scatterers, like rain or fog. Many additional aspects must be considered: inhomogeneity of the atmosphere, pointing errors, variation of the link length along the orbit, presence of clouds, noise due to environmental light. The information-theoretic security criterion proposed in [2] will be adopted, allowing us to take into account finite-key effects, particularly important when considering links based on Low Earth Orbit satellites. Different implementations (continuous and discrete variables) and different protocols are differently affected by the noise. We use a comprehensive model that helps to find the most efficient choice in every scenario.

Q 51.32 Wed 16:15 Redoutensaal

Quantum interference with frequency-locked dissimilar light sources — •Chris Müller[1], Tim Kroh[1], Yanting Teng[2], Andreas Ahlrichs[1], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin — [2]University of Illinois at Urbana-Champaign

To realize a quantum network, it will be necessary to process, store and send photons over long distances. It is unlikely that a single physical system can perform all these operations, therefore, dissimilar quantum systems have to be utilized. The first step towards a quantum network is to show that quantum information can be exchanged between its dissimilar subunits, for instance, via Hong-Ou-Mandel(HOM)-type coincidence measurements [1] on photons emitted by the subunits.

We demonstrate HOM interference between photons from two dissimilar quantum light sources. One is a cavity enhanced spontaneous parametric down-conversion source [2] and the other is a semiconductor quantum dot [3]. In order to establish photon indistinguishability, we frequency-lock both sources to the cesium D1 line (894.3 nm). Active frequency-locking is mandatory to allow for data accumulation over a sufficiently long time and for expanding the quantum network by additional units. We discuss limits of indistinguishability and how it can be improved by additional filtering of the emitted photons in the time domain.

[1] Hong et al., Phys. Rev. Lett. 59, 2044 (1987)
[2] Ahlrichs and Benson, Appl. Phys. Lett. 108, 021111 (2008)
[3] Rastelli et al., Physica Status Solidi B, 249, 687 (2012)

Q 51.33 Wed 16:15 Redoutensaal

Single-photons versus weak-coherent pulses for quantum memories — •Tom Schmit[1], Luigi Giannelli[1], Stephan Ritter[2], Gerhard Rempe[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse , 85748 Garching, Germany

We theoretically analyse the absorption of light incident on a cavity by a single atom within the resonator. We model the atom with a three-level Λ-system and assume that one transition interacts with a single cavity mode while the other is driven by an external laser field. We further include the resonator's and the atom's losses. We then compare the fidelity of absorption when the incident light is a weak coherent pulse and when it is a single photon.

Q 51.34 Wed 16:15 Redoutensaal

A theoretical framework for QR-PUFs — •Giulio Gianfelici, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Physical Unclonable Functions (PUFs) are physical systems with a challenge-response behaviour intended to be hard to clone or simulate. This emerging technology has been proposed in several cryptographic protocols, with particular emphasis on authentication protocols. Recently, extensions of such systems to quantum protocols, the so called Quantum Readout of PUFS (QR-PUF), were suggested. However, a well-defined agreement about theoretical assumptions and definitions behind the intuitive ideas of QR-PUFs, and therefore our ability of characterising the security of cryptographic protocols, is limited. We aim to build a theoretical framework in which we define and quantify the security properties of QR-PUFs. Such a framework will allow us to develop new protocols to derive security thresholds for QR-PUF authentication.

Q 51.35 Wed 16:15 Redoutensaal

Carving of Two-Atom Entangled States using a Cavity — •Bastian Hacker, Stephan Welte, Severin Daiss, Lin Li, Stephan Ritter, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

In a quantum network, optical resonators provide an ideal platform to mediate interactions between matter qubits. This is achieved by the exchange of photons between the resonator-based network nodes, and in this way enables the distribution of quantum states and the generation of remote entanglement. Here we demonstrate how photons can also be used to generate local entanglement between matter qubits in the same network node. Such entangled states are a valuable resource in many quantum communication protocols. We employ neutral atoms, that are strongly coupled to a high-finesse optical cavity. Two protocols are implemented, which rely on the reflection of coherent light from the atom-cavity system. Detection of a polarisation flip heralds the entanglement and postselection allows us to remove parts of the combined two-atom wave function, a method called carving. We created all four Bell-states and achieve fidelities with the ideal Bell states of up to 90%. Our entangling mechanism does not depend on the interatomic distance and can be applied to any matter qubit with a closed optical transition. Furthermore, no individual addressing of the atoms is required. One of the potential applications of the presented entangling scheme is the entanglement swapping procedure in a quantum repeater based on neutral atoms in optical resonators.

Q 51.36 Wed 16:15 Redoutensaal

Sagnac-type setup for the generation of tunable polarization entangled photon pairs — •Golnoush Shafiee[1,2], Gerhard Schunk[1,2], Florian Sedlmeir[1,2], Alexander Otterpohl[1,2], Ulrich Vogl[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]MPL, Erlangen, Germany — [2]Institute of Optics, FAU, Erlangen, Germany — [3]University of Otago, Dunedin, New Zealand

Single photons and photon pairs are an important resource for quantum information processing. Our compact source of photon pairs [1] and squeezed light [2] is based on spontaneous parametric down conversion (SPDC) in a triply resonant whispering-gallery resonator (WGR) made of lithium niobate. Signal and idler radiation inside the resonator have each been demonstrated to be single mode. The central wavelength of the emitted light can be tuned over hundreds of nanometers [3]. Currently, we investigate PDC in counter-propagating modes of a single WGR. We want to show identicality between the counterpropagating signals (or idlers) by studying interference above and below the oscillation threshold.

In this compact and monolithic system, we want to generate identical single photons from two independent sources, which opens up novel possibilities for the creation of polarization-entangled photon pairs for proposed quantum repeater schemes.

[1] M. Förtsch et al., Nat. Commun. 4, 1818 (2013). [2] J. U. Fürst et al., Phys. Rev. Lett. 106, 113901(2011). [3] G. Schunk et al., Optica 2, 773-778 (2015).

Q 51.37 Wed 16:15 Redoutensaal

Two-Atom Quantum Gate employing an Optical Resonator — •Stephan Welte, Bastian Hacker, Severin Daiss, Lin Li, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Optical high-finesse resonators provide an interface between flying photonic qubits and stationary matter qubits [1], which is the foundation of an extended quantum network for quantum communication and distributed quantum computing. For the construction of a scalable network architecture, each node is required to hold several qubits that are connected through quantum gate operations. We present our experiment [2] where such a gate [3] is realized on two neutral Rubidium atoms trapped inside of a strongly coupled optical resonator. The gate itself is mediated by one optical photon, travelling in the network channel of our resonator. This creates an interaction that is independent of the distance between the atoms. We demonstrate the functionality of our gate as a CNOT as well as its ability to entangle the two atoms. The presented gate mechanism has the potential to serve as an entanglement swapping protocol in a future quantum repeater based on cavity QED systems.

[1] A. Reiserer, G. Rempe, *Rev. Mod. Phys.* **87**, 1379 (2015).
[2] S. Welte, B. Hacker, S. Daiss, S. Ritter, G. Rempe, *Phys. Rev. Lett.* **118**, 210503 (2017).
[3] L.-M. Duan, B. Wang, H. J. Kimble, *Phys. Rev. A* **72**, 032333 (2005).

Q 51.38 Wed 16:15 Redoutensaal

Increasing photon collection efficiency for faster remote entanglement of atoms — •Timon Hummel[1], Robert Garthoff[1], Kai Redeker[1], Tim van Leent[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Entanglement of atomic quantum memories separated by large distances will be a key resource for future applications in quantum communication including the quantum repeater and quantum networks. Currently, the efficiency of generation of remote entanglement in schemes based on entanglement swapping is limited by the efficiency of collecting photons from the quantum memory.

Here we present the experimental details on our route for improvement of the photon collection efficiency from a quantum memory based on single trapped atoms. Using a custom designed microscope objective with a high numerical aperture we estimate an improvement of the remote entanglement rate by one order of magnitude relative to that achieved in our previous measurements [1].

[1] Phys. Rev. Lett. 119, 010402 (2017).

Q 51.39 Wed 16:15 Redoutensaal

Heralded Entanglement of Single Atoms over Long Distances — •Tim van Leent[1], Robert Garthoff[1], Kai Redeker[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

The concept of quantum repeaters paves the way towards a scalable quantum network, which is essential for large scale quantum communication and distributed quantum computing. The basis of a quantum network is entanglement between separated quantum memories. One of the current experimental challenges is to generate entanglement over long distances.

Here we present an experimental setup which entangles two Rb-87 atoms separated by a distance of 400 meters. Starting with atom-photon entanglement in both traps, the entanglement swapping protocol is employed to generate heralded entanglement between the atoms [1]. Together with a fast and efficient atomic state readout scheme a loophole-free violation of Bell's inequality was demonstrated [2], which is the key element in advanced protocols, such as certified generation of random numbers and device-independent quantum key distribution.

The next goal is to increase the distance between the entangled atoms. Milestones along this path are increasing the event rate, converting photons to telecom wavelengths, and improving the coherence time of the atomic state.

[1] J. Hofmann, Science 337, 72 (2012)
[2] W. Rosenfeld, Phys. Rev. Lett. 119, 010402 (2017)

Q 51.40 Wed 16:15 Redoutensaal

Entwicklung und Ergebnisse eines deterministischen Einzelionen-Mikroskops — •Felix Stopp, Georg Jacob, Karin Groot-Berning, Kai-Vincent Mettang und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Wir präsentieren die Ergebnisse eines Implantationsexperiments, für das wir eine deterministische Quelle verwenden [1]. Wir haben erfolgreich Stickstoff als NV-Zentren in Diamant implantiert und machen zur Zeit große Fortschritte mit der Implantation von auf 23(7) nm fokussierten $^{141}Pr^{+}$. Mit der Methode des sympathetischen Kühlens via $^{40}Ca^{+}$-Ionen in einer linearen Paulfalle werden uns neue Möglichkeiten eröffnet, z.B. die Implantation von $^{140}Ce^{+}$ oder P^{+} in Silizium (in Zusammenarbeit mit D. Jamieson, http://www.cqc2t.org/). Unsere Messgenauigkeit ist limitiert durch mechanische Vibrationen und thermischen Drifts. Deshalb wird weiterhin die Entwicklung eines hochstabilen Einzelionen-Mikroskops präsentiert. Zwei Ziele eröffnen uns hierbei eine weite Bandbreite an neuen Möglichkeiten: wir wollen Fokusgrößen unter 1 nm und eine Extraktionsrate in der Größenordnung von 1 kHz für schnellen Datenerwerb erreichen. Beide Ziele können durch unsere kompakten und austauschbar steckbaren Module realisiert werden. Hohe Extraktionsraten werden hierbei durch ein Ca^{+}-Reservoir in der Falle erreicht. Von hier aus werden sie zu dem Segment transportiert [2], wo sie zu einer Einzellinse extrahiert werden.

[1] Jacob et al., Phys. Rev. Lett. **117**, 043001 (2016)
[2] Ruster et al., Phys. Rev. A **90**, 033410 (2014)

Q 51.41 Wed 16:15 Redoutensaal

Spin-photon interface controlled switching in a nanobeam waveguide — •Tim Schröder[1], Alisa Javadi[1], Dapeng Ding[1], Martin Hayhurst Appel[1], Sahand Mahmoodian[1], Matthias C. Löbl[2], Immo Söllner[2], Rüdiger Schott[2], Camille Papon[1], Tommaso Pregnolato[1], Søren Stobbe[1], Leonardo Midolo[1], Andreas D. Wieck[3], Arne Ludwig[3], Richard J. Warburton[2], and Peter Lodahl[1] — [1]Niels Bohr Institute, University of Copenhagen, Denmark — [2]Department of Physics, University of Basel, Switzerland — [3]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Coherent control of two-level quantum systems, for example, the electron spin of a solid-state emitter, is an integral requirement for the implementation of quantum information processing. Towards building quantum gates and creating spin-photon entanglement via spin-photon interfaces in photonic integrated circuits (PIC), we demonstrate an efficient, and optically controllable interface between an electron spin in a InGaAs quantum dot and photons guided in a PIC. The spin-state preparation fidelity reaches 96% and allows for the realisation of a proof-of-concept single spin controlled photon switch with a 4-fold switching ratio between ON and OFF states. The spin state lifetime T_1 times reaches 5 μs.

[1] A. Javadi, D. Ding, M. H. Appel, S. Mahmoodian, M. C. Löbl, I. Söllner, R. Schott, C. Papon, T. Pregnolato, S. Stobbe, L. Midolo, T. Schröder, A. D. Wieck, A. Ludwig, R. J. Warburton, and P. Lodahl, arXiv:1709.06369 (2017).

Q 51.42 Wed 16:15 Redoutensaal

Estimating the min-entropy of quantum random processes by exploiting Wigner functions — •Johannes Seiler[1], Thomas Strohm[2], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik & Center for Integrated Quantum Science and Technology IQ^{ST}, Universität Ulm, D-89069 Ulm — [2]Robert Bosch GmbH — [3]Hagler Institute for Advanced Study, Institute forQuantum Science and Engineering (IQSE), and Texas A&M AgriLifeResearch, Texas A&M University, College Station, TX 77843-4242, USA.

An important advantage of a quantum random number generator (QRNG), compared to its classical counterparts, is that quantum mechanics ensures that the generated random numbers are, even in principle, not predictable. However, since QRNG devices are never completely perfect, there is always a classical noise contribution, which in principle allows one to retrieve information about the generated numbers. Hence, a crucial problem is to quantify how much of the data really originates from the underlying quantum mechanical process. This quantity can be expressed in terms of the min-entropy $H_{\min}(B|E)$ of the outcome random variable B conditioned on the environment E. Knowing this quantity, it is possible to create true random numbers from the raw numbers. However, it can be difficult to obtain $H_{\min}(B|E)$, or a good lower bound on it, from measurable quantities. In this poster, we investigate this problem for a simple spin-1/2 system. By using the Wigner function of the system and the measurement operator, we provide new insight into obtaining the optimal lower bound of $H_{\min}(B|E)$.

Q 51.43 Wed 16:15 Redoutensaal

Non-classical correlations between ultra-bright broadband twin beams — •Fabian Gumpert[1,2] and Maria Chekhova[1,2] — [1]Friedrich Alexander Universität, Erlangen, Deutschland — [2]Max Planck Institut für die Physik des Lichts, Erlangen, Deutschland

We investigate non-classical correlations between ultra-bright broadband twin beams. These beams are generated via high-gain parametric down conversion (PDC) in an aperiodically poled lithium niobate crystal. The spectral bands of the idler and signal beams are many times broader than in the case of a uniform (periodically poled) crystal. These ultra-bright broadband twin beams are particularly interesting for quantum information applications. The process of non-phase matched sum frequency generation (SFG) is used to measure the time of photon-number correlations between the twin beams. Because of dispersion effects within the aperiodically poled crystal the photons generated through PDC get additional spectral-dependent delays, which increase the observed correlation time. To reduce the correlation times, additional dispersive elements are added to the setup. A correlation time of 90 fs was recorded until now [1] and by designing the dispersive elements we are going to achieve much shorter correlation times.

[1] M. V. Chekhova, S. Germanskiy, D. B. Horoshko, G. Kh. Kitaeva, M. I. Kolobov, G. Leuchs, C. R. Phillips and P. A. Prudkovskii, arXiv:1710.08330 (2017).

Q 51.44 Wed 16:15 Redoutensaal

Single photon source with rubidium vapor cells — •Arzu Yilmaz — Physikalisches Institut Universität Tübingen, Tübingen, Deutschland

We report on our work towards a single photon source with optical fibers in rubidium vapor cells. Using high laser intensities, we excite the atoms in front of the fiber. This causes a broadening of the atomic fluorescence spectrum beyond the thermal doppler width. As a result, correlations within the fluorescence signal should be observable, which might be used to realize a deterministic single photon source. Such sources are essential for quantum communication protocols and will open up new perspectives in future quantum technology.

Q 51.45 Wed 16:15 Redoutensaal

Ion Implantation and Annealing Parameters and their Effect on Spin Properties of Color Centers in Diamond — •Johannes Lang, Ragul Sivakumar, Christian Osterkamp, Boris Naydenov, and Fedor Jelezko — Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany

The color center in diamond formed by a substitutional nitrogen and an adjacent vacancy (NV center) is amongst the most studied defects in diamond. It is a promising candidate for different applications such as e.g. qubit spin registers in future quantum computation [1] or for different sensing applications [2] as well as quantum communication. Besides the on-demand creation of these color centers by shallow $^{15}N^{+}$ implantation [3], increasing their creation yield and coherence time T_2 are key factors for the applications mentioned above [4]. Here, we present optimizations on our home built, low energy, UHV ion implanter as well as the UHV annealing oven, in combination allowing the creation of single, shallow (< 10 nm) color centers with well controllable properties regarding their implantation depth, density and position. We also present recent investigations on the effect of varying the annealing process parameters and their influence on the created NV centers.

[1] M. W. Doherty et al., Physics Reports 528 1-45 (2013)
[2] C. Müller et al., Nat. Comm. 5 4703 (2014)
[3] S. Pezzagna et al., New J. Phys. 12 065017 (2010)
[4] FF de Oliveira et al., Nat. Comm. 8 15409 (2017)

Q 51.46 Wed 16:15 Redoutensaal

Using Optical Nanofibers for Quantum Optics — •Sarah M. Skoff, Hardy Schauffert, Johanna Hütner, and Arno Rauschenbeutel — Institute of Atomic and Subatomic Physics, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria

Optical nanofibers are a versatile tool for interfacing different quantum emitters with a light field. They are the tapered part of a commercial optical fiber that has a subwavelength diameter waist and therefore allows a significant amount of light to be guided outside the fiber in the form of an evanescent wave. We use such optical nanofibers to optically address individual molecules in solids and we will present this fully fiber-integrated system in more detail.

Due to the transverse confinement of the light field provided by the optical nanofiber, the interaction with quantum emitters is already significant. However this nanofiber-based approach can be combined with a fiber-based cavity to enhance the light-matter interaction even further and we will show the implementation of such a resonator.

Q 51.47 Wed 16:15 Redoutensaal

Collective molecular emission into a nanofiber — •Masoud Mirzaei[1,2], Tobias Utikal[1,2], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University of Erlangen-Nürnberg, Erlangen, Germany

Tapered optical fibers with a subwavelength diameter exhibit a highly confined mode with a pronounced evanescent field. These properties result in efficient coupling between emitters along the fiber and the guided mode and make it highly desirable for sensitive absorption and fluorescence spectroscopy. In this work, we report mirror-less, low-threshold laser-like action from an organic gain medium surrounding the nanofiber. We discuss variations in temporal and spectral widths as a function of the excitation pulse energy as well as a threshold in the emission signal in the context of self-absorption and re-emission.

Q 51.48 Wed 16:15 Redoutensaal

SiO2 on Si photonic platform with ultra-low intrinsic fluorescence for integrated single photon emitters based on diamond defect centers — •Florian Böhm[1], Christoph Pyrlik[2], Niko Nikolay[1], Jan Schlegel[2], Andreas Thies[2], Andreas Wicht[2], and Oliver Benson[1] — [1]AG Nanooptik, Humboldt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institut für Höchstfrequenztechnik, Berlin, Germany

On-chip photonic structures, for example integrated solid-state single photon sources, effectively coupled to a single guided optical mode are one important tool towards future applications in quantum information science [1]. Typically excitation and fluorescence collection from single emitters requires bulky confocal microscopes.

We report on our approach towards an integrated single photon source, consisting of nano-sized quantum emitters (NV centers in diamond), evanescently coupled to photonic structures in SiO2. This novel hybrid system, based on pure, undoped SiO2, exhibits exceptionally low intrinsic fluorescence and allows high reproducibility and diversity in the fabrication of photonic elements e.g. waveguides, mode-size converters, couplers and resonators.

Our results are promising steps towards realizing a fully integrated single photon source. Deterministic [2] coupling of a single quantum emitter to the system could enable simultaneous on-chip excitation and collection, rendering the microscope objective unnecessary.

[1] Aharonovich, I., et al., Nature Photonics, 10(10), 631-641, (2016)
[2] Schell A.W., et al. Rev. Sci. Instrum., 82(7), 073709, (2011)

Q 51.49 Wed 16:15 Redoutensaal

Nano-Quantum Optics — •Vahid Sandoghdar[1,2] and Stephan Götzinger[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Erlangen — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg

The interaction of light and matter at the nanometer scale lies at the heart of quantum optics because it concerns elementary processes such as absorption or emission of a photon by an atom. These phenomena were studied with ensembles of light and material particles in the 20th century. However, controlled and efficient experiments with single photons and single quantum emitters have only recently become accessible. This advance owes much to the progress in the field of nano-optics, where the interaction of individual quantum emitters such as molecules, quantum dots or color centers with their nanoscopic environment can be tailored. In this poster presentation, we provide an overview of the exciting field of nano-quantum optics and its promise for engineering new quantum states of light and matter.

Q 51.50 Wed 16:15 Redoutensaal

Strong enhancement of radiative decay and efficient biexciton emission from a single quantum dot coupled to a plasmonic nanocone antenna — •Hsuan-Wei Liu[1], Korenobu Matsuzaki[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, Erlangen, Germany

Semiconductor quantum dots are capable of emitting one, two or more photons after each excitation because of the possibility of generating multiple excitons within the same quantum dot. In the case where two excitons are created, recombination leads to a cascaded emission process. However, the quantum efficiency of such a two-photon emission is usually very low. In this study, we demonstrate a significant enhancement of the biexciton emission efficiency by coupling a single quantum dot to a plasmonic nanocone antenna, which was fabricated by focused ion beam milling [1]. We show that the quantum efficiency of the biexciton emission is increased by more than one order of magnitude to 70% in the coupled system. Moreover, by performing many quantitative in-situ measurements on the same quantum dot, we demonstrate more than 100-fold radiative enhancement by the gold nanocone antenna for both excitonic and biexcitonic emission channels [2].

[1] Hoffmann *et al.*, *Nanotechnology* **26**, 404001 (2015). [2] Matsuzaki *et al.*, *Sci. Rep.* **7**, 42307 (2017).

Q 51.51 Wed 16:15 Redoutensaal

Nanodiamonds manipulation with AFM at nanoscale — •Yan Liu, Alexander Kubanek, and Fedor Jelezko — Institut für Quantenoptik, Universität Ulm

Nanodiamonds (ND) embedded with optically active colour centres have important applications. They are now widely used as bio-imaging makers at different wavelengths. in addition, they are excellent platforms for quantum optics study. Here we show the technique of manipulating nanodiamonds at nanoscale. Our experimental setup is the combination of AFM and a confocal fluorescence microscope also incorporated with synchronized microwave source, and it allows us to study the sizes of NDs, fluorescence properties and spin properties of negatively charged nitrogen vacancy colour centres in the NDs. Besides that, we can do repositioning with accuracy of about 20 nm and orientation flipping of the NDs using contact mode of the AFM. The results promote further studies on dipolar coupling of single photon emitters and spin-spin coupling of quantum platforms in different NDs, engineering integrated quantum optical circuits, etc.

Q 51.52 Wed 16:15 Redoutensaal

^{13}C enriched nanodiamonds — •yuliya mindarava[1], yan liu[1], vyacheslav agafonov[2], valeriy davydov[3], liudmila kulikova[3], christian laube[4], christian jentgens[4], and fedor jelezko[1] — [1]Institute of Quantum Optics, Ulm University, Ulm, Germany — [2]François Rabelais University, Tours, France — [3]L.F. Vereshchagin Institute for High Pressure Physics of the RAS, Troitsk, Russia — [4]Leibniz Institute of Surface Engineering, Leipzig, Germany

Nuclear hyperpolarization can be realized with nitrogen-vacancy (NV) color center incorporated with ^{13}C in nanodiamonds, which can be used as labels for magnetic resonance imaging (MRI). In this work, we employed a combined setup consisting of an atomic force microscope (AFM), a confocal fluorescence microscope, a microwave source, and a spectrometer to study ^{13}C incorporated NV centers in nanodiamonds (ND). Enrichment of ^{13}C in ND was analysed with optically detected magnetic resonance (ODMR) of NV centers. Sizes, fluorescence spectra, and fluorescence intensities of NDs can all be acquired. Therefore, we are able to calculate the density of NV centers. With hyperpolarization of ^{13}C and surface functionalization in the future, our study would promote targeted MRI, which owes great significance in medical and biological applications.

Q 51.53 Wed 16:15 Redoutensaal

XUV Microscopy with a Schwarzschild-Objective driven by high-harmonic generation — •Felix Wiesner[1], Julius Reinhard[1], Martin Wünsche[1,2], Johann Jakob Abel[1], Silvio Fuchs[1,2], Jan Nathanael[1], Christian Rödel[2], and Gerhard Paulus[1,2] — [1]Institute of Optics and Quantum Electronics Jena, Germany — [2]Helmholtz Institute Jena, Germany

We report on the development of an extreme ultraviolet light (XUV) microscope with a Schwarzschild objective (SSO). XCT is a 3D imaging technique, which is based on Optical Coherence Tomography and was realized using Synchrotron radiation sources [1] as well as a lab-scale high-harmonic XUV source [2,3]. The axial resolution of XCT reaches a few nanometers, whereas the lateral resolution is limited by the size of the focal spot, 23μm at present. To overcome this significant gap a special high-NA SSO is used. The SSO consist of two spherical mirrors and offers almost aberration-free imaging with a NA of 0.2 supporting lateral resolutions down to 70nm. The two optics have a broadband multilayer coating, a prerequisite of XCT. To test the imaging properties of the SSO, a transmission light microscopy setup has been built. With this setup, a pinhole and diffractive gold gratings were investigated as well as gold nanoparticles, carbon nanotubes and cancer cells. In first experiments, resolutions below 1μm have been reached. A combination with XCT is possible for thin samples and allows non-destructive 3D imaging with nanometer resolution in all dimensions. [1] Fuchs et al., Scientific Reports 6, 20658 (2016) [2] Fuchs et al., Optica 4, 903 (2017) [3] Wünsche et al., Optics Express 25, 6936 (2017)

Q 51.54 Wed 16:15 Redoutensaal

Infrared streak cameras: Overcoming low SNR by upconversion — •Markus Allgaier[1], Vahid Ansari[1], Christof Eigner[1], Viktor Quiring[1], Raimund Ricken[1], John Matthew Donohue[1], Thomas Czerniuk[2], Marc Assmann[2], Manfred Bayer[2], Benjamin Brecht[3,1], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn, Germany — [2]Experimentelle Physik II, Technische Universität Dortmund, 44221 Dortmund, Germany — [3]Clarendon Laboratory, Department of Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Streak cameras are the standard tool for studying semiconductor emission in the time domain, especially for picosecond time scales. While high performance on the single-photon level has been shown for visible wavelengths, sensitivity and noise performance for the infrared range is limited. We study noise sources and quantum efficiency in commercially available streak cameras, and show that the limitations in the infrared and particularly the telecom range can be overcome using an upconversion scheme. We experimentally demonstrate single-photon sensitivity in the telecom band using an engineered sum-frequency generation process in periodically poled Titanium-indiffused waveguides in Lithium Niobate, achieving picosecond resolution. Single-photon sensitivity is verified using a parametric downconversion (PDC) source with a known average photon number of 0.2.

Q 51.55 Wed 16:15 Redoutensaal

Topological order in finite-temperature and driven dissipative systems — •Lukas Wawer[1], Michael Fleischhauer[1], Charles Bardyn[2], Sebastian Diehl[3], and Alexander Altland[3] — [1]University of Kaiserslautern, Kaiserslautern, Germany — [2]Department of Quantum Matter Physics, University of Geneva — [3]University of Cologne, Cologne, Germany

There are many exciting topological properties of topological systems in pure states. Although mixed quantum states can be understood as a generalization of pure states their topological properties are not investigated so far. For example, quantization of charge transport in a so-called Thouless adiabatic pump is lifted at any finite temperature in topological insulators. Here we show, that many body correlations preserve the integrity of topological invariants for mixed Gaussian states in one dimension. In our approach we show that the expectation value of the many body momentum-shift operator leads to a definition of a physical observable called the "ensemble geometric phase" (EGP). It turns out that in analogy to the Zak phase of pure states this phase is a general representation of a geometric phase for mixed Gaussian quantum states in the thermodynamic limit. Additionally the EGP provides a topologically quantized observable which detects encircled spectral singularities of density matrices. [1] Bardyn et. al., arXiv:1706.02741v2

Q 51.56 Wed 16:15 Redoutensaal

Seeded Photon Triplet Generation — •Cameron Okoth[1], Andrea Cavanna[1], Nicolas Y. Joly[1,2], and Maria V. Chekhova[1,2,3] — [1]Max-Planck- Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Faculty of Physics, M. V. Lomonosov Moscow State University, 119991 Moscow, Russia — [3]University of Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany

As quantum systems become more integrated in commercial and industrial technologies, it is only natural to find the limitations of what we can experimentally achieve with regards to these systems. One particular area of interest is the generation of high number Fock states beyond single and pair states. We intend to produce a three photon state via cubic non-linearity in which a pump photon decays into three daughter photons.

We make a theoretical comparison of the expected photon triplet rates, both when the generation of the photon triplet state is spontaneous, and when the process is stimulated by supplying photons in one of the modes of the photon triplet state. By introducing a parameter known as the effective vacuum field it is possible to set-up some general statements about the relative efficiency of each process. By maximising the variables that enter photon triplet rate equation, we suggest several promising materials that can be exploited to generate photon triplets with reasonable rates.

Q 51.57 Wed 16:15 Redoutensaal

Characterization of Optically Dense Atomic Ensembles confined in Nanofiber-based traps — •Samuel Rind, Adarsh Prasad, Jakob Hinney, Christoph Clausen, Jürgen Volz, Philipp Schneeweiss, and Arno Rauschenbeutel — srind@tuwien.ac.at

Nanofiber based traps have been used for the last decade as novel interface between light and matter. Here we realize an efficient optical interface between fiber-guided light and laser-cooled atoms, which are arranged in two linear arrays in a two-color evanescent-field dipole trap around an optical nanofiber. In this configuration, we achieve a strong light-matter interaction where the probability of a nanofiber-guided photon being absorbed by a trapped atom is as high as 10%. To see this, we measure the transmission through the fiber as we scan the frequency of our probe field. When large ensembles of atoms are trapped (several 1000) this gives rise to a high optical density (OD) around the fiber. As a consequence, even for large detuning (>100MHz) from the atomic resonance the atoms completely scatter light. This makes accurate and quick measurements of OD difficult with standard instruments, such as an acousto-optic modulator (AOM), which typically have frequency scan ranges below 200MHz. Here, we implement an electro-optic modulator (EOM) based frequency scanning scheme that allows us to scan a range that exceeds 1GHz in our experimental time frame of 5ms easily. This enables us to measure OD well over 1000, vastly improving previous incarnations we had of OD measurement schemes.

Q 51.58 Wed 16:15 Redoutensaal

Limits on generating higher-order Fock states with parametric down conversion — •Johannes Tiedau[1], Tim J. Bartley[1], Georg Harder[1], Thomas Gerrits[2], and Christine Silberhorn[1]

— [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA

Photon number (Fock) states are of both fundamental and practical interest. They are used as resources in quantum metrology schemes, and can be used to probe the boundary between quantum and classical phenomena. In general, the metrological advantages and photonic state regimes of interest scale with the number of photons, therefore generating higher-order Fock states n, where n>2, is required. To date, nonlinear interactions such as heralded parametric down conversion are the standard method to generate such states. However, the probabilistic nature of the down-conversion process leads to a fundamental trade-off between generation probability and fidelity of the final states to the desired Fock states. For single photon Fock states, generated in this way, it is known that the maximal generation probability is 25%. Here, we generalise this result to cover higher order Fock states, taking into account the possible spectral multimode nature of the PDC state. The generalisation is non-trivial as all combinatorial possibilities to generate n photons from m possible modes need to be considered. This is supported by experimental data demonstrating the trade-off in the case where a spectrally optimised source is used.

Q 51.59 Wed 16:15 Redoutensaal

Observing $g^{(2)}(0)$ at the lasing threshold with samplerates up to 1 MHz — •Johannes Thewes, Carolin Lüders, and Marc Assmann — Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany

Monitoring fast changes in the photon statistics of a light source, such as a diode laser driven close to its lasing threshold, demands a high speed evaluation of the second order correlation function $g^{(2)}(0)$. By employing an optical homodyne detection scheme, we achieved samplerates of up to 1 MHz for $g^{(2)}(0)$. Thus, we could observe how and on what time scales the light emitted from a diode laser driven close to its lasing threshold switches back and forth between Poissonian and super-Poissonian photon statistics, which indicate coherent and thermal light respectively. In this way, we are able to perform a detailed analysis of the coherence dynamics at the lasing threshold. In sum, our work demonstrates the feasibility of sampling $g^{(2)}(0)$ with up to 1 MHz and enables future research and applications with other light sources such as polaritons in microcavities or optical quantum memories.

Q 51.60 Wed 16:15 Redoutensaal

Generation of squeezed vacuum states in a nonlinear crystalline whispering gallery mode resonator — •Alexander Otterpohl[1,2], Florian Sedlmeir[1,2], Thomas Dirmeier[1,2], Ulrich Vogl[1,2], Gerhard Schunk[1,2], Golnoush Shafiee[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Tobias Gehring[4], Ulrik L. Andersen[4], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nürnberg, Staudtstr. 7 B2, 91058 Erlangen, Germany — [3]The Dodd-Walls Centre for Photonic and Quantum Technologies, Department of Physics, University of Otago, 730 Cumberland Street, 9016 Dunedin, New Zealand — [4]Department of Physics, Technical University of Denmark, Fysikvej, 2800 Kgs. Lyngby, Denmark

Macroscopic crystalline whispering gallery mode resonators (WGMR) made out of $LiNbO_3$ are a versatile source of non-classical light generated via optical parametric down-conversion [1]. Previously, we demonstrated squeezing of a bright single parametric beam as well as twin-beam squeezing above threshold. Now, we operate our source below the oscillation threshold at the degenerate point to generate squeezed vacuum states. We currently achieve up to 1 dB squeezing closely below threshold, which corresponds to only tens of microwatts of pump power. The low threshold allows us to investigate squeezing in a regime closely above and below the threshold.

[1] J. U. Fürst et al., Phys. Rev. Lett. **106**, 113901 (2011).

Q 51.61 Wed 16:15 Redoutensaal

Towards integrating superconducting detectors on lithium niobate waveguides — •Jan Philipp Höpker[1], Frederik Thiele[1], Moritz Bartnick[1], Stephan Krapick[1], Evan Meyer-Scott[1], Nicola Montaut[1], Harald Hermann[1], Raimund Ricken[1], Viktor Quiring[1], Torsten Meier[1], Adriana Lita[2], Varun Verma[2], Thomas Gerrits[2], Richard Mirin[2], Sae Woo Nam[2], Christine Silberhorn[1], and Tim Bartley[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]National Institute of Standards and Technology, 325 Broadway, Boulder, CO, 80305, USA

Superconducting photon detectors and integrated optics have enabled a variety of quantum optical experiments. Lithium niobate is a promising platform for quantum photonics thanks to its large second order nonlinear susceptibility, large electro-optic coefficient, and low guiding losses. Therefore, lithium niobate works very well for fast modulation and single photon sources. However, detecting single photons inside lithium niobate waveguides remains a challenge. Fiber-coupled superconducting nanowire single photon detectors (SNSPDs) and transition edge sensors (TESs) show outstanding quantum efficiency with low dark count rates. We have taken the initial steps in depositing these detectors on lithium niobate waveguides, including room temperature absorption measurements, cryogenic flood illumination tests, and the investigation of fiber-pigtailing for cryogenic environments.

Q 51.62 Wed 16:15 Redoutensaal

Entangled Photons Recombination from Broadband Parametric Down Conversion — •Hani Abou Hadba[1,2,3], Kirill Spasibko[2,3], and Maria chekhova[2,3] — [1]School of Advanced Optical Technologies SAOT, Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [3]Max-Planck-Institut für die Physik des Lichts, Erlangen Germany

Parametric down-conversion (PDC) is widely used as a source of entangled photon pairs, which have numerous applications in quantum optics and quantum information. The reverse process to PDC is the sum frequency generation (SFG): while in PDC a pump photon decays into a photon pair, in SFG two photons recombine into one. This process is referred to as the pump re-construction as it gives arise, apart from a broad spectral background, to a narrow peak at exactly the pump wavelength. The background originates from photons belonging to different pairs.

In this work we study how the height of the recombination peak with respect to the back-ground depends on the number of entangled frequency modes. We show that the ratio between the peak and the background could be used as a measure of the number of modes and therefore a measure of entanglement.

Q 51.63 Wed 16:15 Redoutensaal

Amplification of high orbital angular momentum modes in a nonlinear interferometer — •Johan Ospina[1,2], Roman Zakharov[3], Olga Tikhonova[3], and Maria Chekhova[1,2,3] — [1]Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058 Erlangen, Germany — [2]University of Erlangen-Nürnberg, Staudtstrasse 7/B2, 91058 Erlangen, Germany — [3]Department of Physics, M. V. Lomonosov Moscow State University, Leninskie Gory, 119991 Moscow, Russia

We study the orbital angular momentum (OAM) modes of bright squeezed vacuum (BSV). BSV is produced via high-gain parametric down conversion and it manifests quantum features despite its high (macroscopic) numbers of photons. In particular, its modes with opposite OAM values have the same photon numbers and therefore it is possible to observe quantum correlations between them. However, the observation of such correlations requires the efficient lossless sorting of OAM modes. Because the sorting of higher-order modes with opposite OAM values is easier, we are going to shape the spectrum of BSV in such a way that low-order OAM modes are suppressed. For this we use a Michelson-type nonlinear interferometer where BSV is generated in a nonlinear crystal and then gets reflected back into the same crystal together with the pump, which takes a separate path. By using additional optical elements inside the interferometer we provide the selective amplification of specific OAM modes. The OAM spectrum is studied by analysing the photon-number correlations in the output angular spectrum.

Q 51.64 Wed 16:15 Redoutensaal

Precise frequency estimation using a quantum sensor — Simon Schmitt[1], •Daniel Louzon[1,2], Tuvia Gefen[2], Liam McGuinness[1], Alex Retzker[2], and Fedor Jelezko[1] — [1]Institute of Quantum Optics, University of Ulm, Ulm, Germany — [2]Racah institute of Physics, the Hebrew University of Jerusalem, Jerusalem , Israel

Precision measurements play an important part in many of today's aspects of research, and are becoming an especially important part of the emerging field of quantum sensing. Reaching higher precision is paramount to gain meaningful information from such measurements with the majority of quantum sensing focused on optimizing the amplitude sensitivity to external field.

In this work use nitrogen vacancy center in diamond, as a single atom quantum sensor, in concert with dynamical decoupling to optimize the frequency precision with which an oscillating field can be detected. We show that given an AC signal with some knowledge on its frequency we can maximize the information we can gather on that frequency given some interaction time with our quantum sensor.

We also show, that the scaling of the Fisher Information about this frequency in this case is T^4 (T being the interaction time), which is the best purposed by theory. We show that this method is the best available method in the case of decoherence free subspace, or the more realistic case of a signal with short time phase correlations.

Q 51.65 Wed 16:15 Redoutensaal

3D printing of complex submillimeter-sized wide angle objectives — •Zhen Wang[1], Simon Thiele[2], Ksenia Weber[1], Chenyang Zhang[1], Alois Herkommer[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institute of Technical Optics and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 9, 70569 Stuttgart, Germany

Compact image sensors with a variety of focal lengths, fields of view, and other optical parameters, will be the enabling technology of integrated devices for industry 4.0. In order to miniaturize the imaging devices from currently several mm^3 to below 1 mm^3, and to achieve diameters of the optics below 1 mm, 3D printing with femtosecond laser pulses is the method of choice. Here, we present several multi-lens designs as well as printed objectives with fields of view that range from 80° to 120°, and focal lengths in the range of 200-300 μm, with diameters around 800 μm, which allow for wide-angle imaging. We characterize their performances and report how to overcome some issues when printing such challenging designs. In the future, those objective can be directly printed onto CMOS imaging chips which will enable very compact image sensors.

Q 51.66 Wed 16:15 Redoutensaal

How to superimpose six light waves without interference — •Koen van Kruining[1], Rob Cameron[2], and Jörg Götte[3] — [1]Max Planck Institut für Physik komplexer Systeme, Dresden — [2]University of Strathclyde, Glasgow, UK — [3]Nanjing university, Nanjing, China

We present a set of superpositions of up to six plane light waves which have a homogeneous electric field strength. For most physical processes, including human eyesight, these superpositions can be considered noninterfering. Because of the homogeneity of the electric field strength effects beyond the electric dipole interaction become noticeable and the lights inhomogeneous helicity can be probed. Among others, our superpositions allow for writing a variety of periodic patterns in liquid crystalline polymers and to make periodic traps for birefringent particles suspended in water.

Q 51.67 Wed 16:15 Redoutensaal

3D printed combinations of fibers with complex optics for virtual and augmented reality applications — •Philipp Geser[1], Simon Ristok[1], Simon Thiele[2], Alois Herkommer[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Stuttgart — [2]Institute for Applied Optics and Research Center SCoPE, University of Stuttgart, Stuttgart

Virtual and augmented reality systems should be compact and virtually invisible to the outside observer. Clumsy goggles which are the standard right now do not fulfill these requirements. We combine fiber optics with 3D printed complex microoptics in order to realize a highly compact VR/AR system and demonstrate its use.

Q 51.68 Wed 16:15 Redoutensaal

Towards a whispering gallery mode resonator based wavemeter — •Thomas Halbauer[1,2], Golnoush Shafiee[1,2], Gerhard Schunk[1,2], Alexander Otterpohl[1,2], Florian Sedlmeir[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nürnberg, Staudtstr. 7 B2, 91058 Erlangen, Germany — [3]The Dodd-Walls Centre for Photonic and Quantum Technologies, Department of Physics, University of Otago, 730 Cumberland Street, 9016 Dunedin, New Zealand

Macroscopic crystalline whispering gallery mode resonators (WGMR) can provide the possibility for a whispering gallery type wavemeter (WGTW) in just one monolithic device. The frequency spacings between different modes of the WGMR represent a unique fingerprint of the frequency of the exciting laser. We use an electro-optic frequency tuning mechanism to shift the fingerprint of an unknown source with fixed frequency. The accuracy is only limited by the linewidth of resonances. In combination with our experimental resonance frequency analysis [1], this unambiguously reveals the excitation wavelength. For achieving the required temperature stability, we implement a scheme based on the differential shift between TE and TM modes of an additional locking laser.

[1] G. Schunk *et al.*, Opt. Express **22**, 30795 (2014).

Q 51.69 Wed 16:15 Redoutensaal

Towards amorphous superconducting single-photon detectors integrated with nanophotonic waveguides — •Matthias Häussler[1,2], Martin A. Wolff[1,2], Wolfram H. P. Pernice[1,2], and Carsten Schuck[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany

Future applications in photonics and quantum communication strongly depend on the development of suitable single-photon detectors. Superconducting nanowire single-photon detectors (SNSPDs) are among the most promising candidates offering high efficiency and bandwith at low noise and jitter.

Superconducting nanowires made from nanocrystalline superconducting materials such as NbN feature excellent electrical performance when grown on suitable substrates. Recently similar performance in terms of single-photon detection has also been achieved with amorphous superconducting films, which adapt to a wider range of substrates.

Here we aim for realizing SNSPDs made from amorphous molybdenum silicide (MoSi) superconducting films on dielectric material systems that are well suited for the fabrication of photonic integrated circuits. We present a cryogenic measurement system for testing the single-photon detection capabilities of MoSi thin films. Waveguide integrated SNSPDs are prototyped using standard nano-fabrication routines and performance tests are presented.

Q 52: Cold atoms VI - traps (joint session A/Q)

Time: Thursday 10:30–12:15 Location: K 0.011

Q 52.1 Thu 10:30 K 0.011

Dipole trapping in the absence of gravity — •Christian Vogt[1], Marian Woltmann[1], Sven Herrmann[1], Claus Lämmerzahl[1], and The PRIMUS-Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM), 28359 Bremen — [2]Institut für Quantenoptik, LU Hannover

Cold atoms have proven to be a useful toolbox with wide applications in testing the fundamentals of physics, e.g the weak equivalence principle which provides the cornerstone of Einstein's general relativity theory [1]. In the recent years great effort has been made to take advantage of these techniques in weightlessness. For example the first BEC in space was created and effective temperatures down to the pK regime were demonstrated in the drop tower in Bremen [2]. So far all of these result from atoms held in magnetic traps on atom chips. This talk will be about the first realization of a dipole trap in weightlessness. Proven its worth on ground , dipole traps have never before been operated in microgravity, although they can produce high number BECs and have unique advantages like the ability to apply feshbach resonances. Our experiment, the PRIMUS project, uses the drop tower in Bremen witch offers up to 4.7s of microgravity time in drop mode. The talk will focus on the dimension of evaporation and the reduction of evaporation time. The PRIMUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1642. [1] D. Schlippert et al., Phys. Rev. Lett. 112, 203002 (2014) [2] Jan Rudolph,(PhD Thesis), Leibniz University Hannover, 2016.

Q 52.2 Thu 10:45 K 0.011

A high repetition deterministic ion source — •Cihan Sahin, Philipp Geppert, Adreas Müllers, and Herwig Ott — Technische Universität Kaiserslautern

An ion source with minimal energy spread and deterministic operability has many possible applications in basic research and technical applications including surface spectroscopy, ion microscopy, ion implantation or milling. Key requirements for these applications include among others a high degree of control of ion trajectories and high rates.

We developed an ion source capable of delivering ions on demand with high fidelity. The basis of our ion source is a magneto-optical trap (MOT) of ^{87}Rb atoms. The atoms are photoionized by a three photon process within a small volume inside the MOT. A symmetric detector setup for electrons and ions allows to detect the ionization fragments.

We can classify the operation of the source in three modes. In the single ion operation mode the electron is used to switch for a short time a gating electrode on and so let the corresponding ion pass. With an additional external trigger deterministic operation mode is enabled and single ions are provided on demand with high fidelity around a rate of $10\,000\,\mathrm{s}^{-1}$. The source can also be used in the continuous operation mode delivering ions with a rate of $1 \times 10^6\,\mathrm{s}^{-1}$.

Q 52.3 Thu 11:00 K 0.011

Time-dependent custom tailored optical potentials — •Lukas Palm, Marvin Holten, Philipp M. Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Engineering quantum states of ultracold atoms requires precise control over the confining potentials. Spatial light modulators displaying computer generated holograms are readily employed to spatially shape such optical potentials in a wide variety of geometries. However, their capabilities in the time domain are severely restricted by the refresh rate of the device.

We utilize multiple optical modes with a relative detuning to realize time-dependent potentials where RF control of the optical frequencies allows a wide range of modulation rates. This allows the creation of rapidly rotating traps where high angular momenta and strongly correlated states are accessible. Therewith we want to realize quantum Hall physics in a few fermion system.

Q 52.4 Thu 11:15 K 0.011

Thermodynamics of a non-equilibrium single-atom system — •Daniel Mayer[1], Daniel Adam[1], Quentin Bouton[1], Steve Haupt[1], Tobias Lausch[1], Felix Schmidt[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

We report on the experimental investigation of phase space dynamics of individual atoms, quenched out of equilibrium by a Raman cooling pulse. We numerically model our findings by using an effective two-temperature approach, yielding excellent agreement with the experimental data. For application of multiple pulses, we observe the approach of a thermal state with a new temperature.

Experimentally, we prepare a few atom sample of laser cooled Cs atoms in a crossed, optical dipole trap. We apply a pulse of degenerate Raman sideband cooling, thereby quenching the phase space distribution of the sample. The dynamics emerging after the quench is observed by two distinct methods: we extract information about the radial momentum distribution by a release-recapture experiment while in axial direction we use fluorescence imaging in a 1D optical lattice to observe the atomic position distribution.

Q 52.5 Thu 11:30 K 0.011

Precision measurement of the dynamical polarizability of dysprosium at 1064nm — Cornelis Ravensbergen[1,2], •Vincent Corre[1,2], Elisa Soave[2], Marian Kreyer[1,2], Slava Tzanova[1,2], Emil Kirilov[2], and Rudolf Grimm[1,2] — [1]Institut für Quanten Optik und Quanten Information, Innsbruck — [2]Institut für Experimental Physik, Universität Innsbruck

The field of ultracold dipolar gases has grown vastly in the last years, motivated by the new phases made accessible by the long-range anisotropic dipole-dipole interaction. Among dipolar systems, atomic gases of lanthanides - erbium and dysprosium - have been cooled down to the degenerate regime and have demonstrated striking dipolar effects. But while the geometry of the trapping potential is known to have a critical influence on the behavior of these gases, questions remain about the value of the dynamical polarizability of dysprosium, as a large discrepancy still exists between theoretical calculations and experimental measurements. We report on a new measurement of the dynamical polarizability of dysprosium at 1064 nm with unprecedented precision. We take advantage of our dual-species experimental set-up and use potassium as a reference species. By calibrating the polarizability of dysprosium on the one of potassium, which is well known, we free ourselves from the main sources of systematic error that are the trapping laser waist and aberrations, and anharmonicity effects. We check that other possible error sources have negligible effect. Eventually we obtain values for the scalar and tensor parts of the polarizability with a relative error of 2%, that are close to the theoretical predictions.

Q 52.6 Thu 11:45 K 0.011

Tuning collective dipole-dipole interactions via cavities — •Helge Dobbertin and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany

When resonant atoms are confined inside a volume smaller than the transition wavelength λ cubed, they couple via strong dipole-dipole interactions and show a collective response to near-resonant light. Recent studies [1] found that the resulting line shifts of cold atomic gases substantially differ from the textbook Lorentz-Lorenz effect. At finite temperature [2] an additional density dependent shift occurs due to collisions.

Here, we discuss possibilities to tune the dipole-dipole interactions by means of macroscopic cavity geometries. This may offer a new handle to separate collisional and dipole-dipole induced shifts and to study the microscopic basis of local-field corrections in cold and thermal atomic ensembles [3].

[1] J. Pellegrino et al., Phys. Rev. Lett. **113**, 133602 (2014).
[2] J. Keaveney et al., Phys. Rev. Lett. **108**, 173601 (2012).
[3] J. Javanainen et al., Phys. Rev. A **96**, 033835 (2017).

Q 52.7 Thu 12:00 K 0.011

Dipolar quantum droplets and striped states — •Fabian Böttcher, Matthias Wenzel, Jan-Niklas Schmidt, Michael Eisenmann, Tim Langen, Igor Ferrier-Barbut, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

The dipolar interaction allows for self-organized structure formation similar to the Rosensweig instability in classical ferrofluids. In our experiments with quantum gases of Dysprosium atoms, we observe a phase-transition between a gas and a liquid, characterized by the formation of self-bound droplets. In contrast to theoretical mean field predictions the superfluid droplets did not collapse. We confirmed experimentally that this unexpected stability is due to beyond mean field quantum corrections of the Lee-Huang-Yang type. These droplets are 100 million times less dense than liquid helium droplets and open new perspectives as a truly isolated quantum system.

Under strong confinement in one dimension, we observe the formation of an array of stripes. We also study striped ground states theoretically and outline prospects to reach a phase coherent supersolid ground state.

In a further ongoing experiment we rotate the droplets by a spinning magnetic field and observe that they can be rotated faster than the transverse trapping frequency due to a surface tension counteracting the centrifugal force. We also observe the excitation of a scissors mode of the droplets.

Q 53: Quantum Optics and Photonics III

Time: Thursday 10:30–12:30 Location: K 0.016

Q 53.1 Thu 10:30 K 0.016

Waveguide-integrated superconducting nanowire single photon detectors — •Simone Ferrari[1,2], Fabian Beutel[1,2], and Wolfram Pernice[1,2] — [1]University of Münster, Institute of Physics, Germany — [2]University of Münster, CeNTech - Center for Nanotechnology, Germany

Nanophotonic technology empowers the realization of low-loss, small-footprint and scalable hybrid architectures for generating, manipulating and detecting single photons [1]. Thanks to their high efficiency, wide optical detection bandwidth, fast response and low timing uncertainty, waveguide-integrated superconducting nanowire single photon detectors represent a catalyst for the development of quantum technology and life science. We show our recent achievement on the integration of single photon detector devices to complex nanophotonic architectures. We demonstrate the realization of a fully integrated device with electrically driven single photon emitters and single photon detectors [2]. To overcome the inability for superconducting detectors to resolve photon energy, we integrate eight detectors in a multi-channel arrayed waveguide grating realizing a fully integrated single-photon spectrometer [3] and, as further improvement, we demonstrate an on-chip quantum limited heterodyne detection technique with ultra-high spectral resolution [4]. [1] Science 318 (5856), 1567 (2007) [2] Nature Photonics 10, 727 (2016) [3] Optica 4 (5), 557 (2017) [4] Scientific Reports 7, 4812 (2017)

Q 53.2 Thu 10:45 K 0.016

Hot-spot relaxation time current dependence in niobium nitride waveguide-integrated superconducting nanowire single-photon detectors — •Simone Ferrari[1], Vadim Kovalyuk[2], Gregory Gol'tsman[2], and Wolfram Pernice[1] — [1]University of Münster, Institute of Physics, Germany — [2]Moscow State Pedagogical University, Department of Physics, Russia

Superconducting nanowires detectors embedded in nanophotonic circuitry provide an attractive solution for on-chip fast and efficient single-photon detection. Their working principle is based on the localized destruction of superconductivity, called hot-spot, after the absorption of a photon, which generates a recordable electrical pulse. To investigate the ultimate detection timescale for these devices, we adopt a pump-probe technique in the near-infrared region [1,2]. We study the bias current dependence of the hot-spot temporal dynamic for niobium-nitride superconducting nanowire single photon detectors atop silicon nitride waveguides. Our study reveals a strong increase of the picosecond relaxation time with increasing bias current. A minimum relaxation time of 22 ps is obtained when applying a bias current of 50% of the switching current at a bath temperature of 1.7K. [1] Phys. Rev. B 93, 094518 (2016) [2] Optics Express 25 (8), 8739 (2017)

Q 53.3 Thu 11:00 K 0.016

Shape fidelity of 3D printed microoptics — •Simon Ristok[1], Simon Thiele[2], Timo Gissibl[3], Alois Herkommer[2], and Harald Giessen[1] — [1]4. Physikalisches Institut, Universität Stuttgart — [2]Institut für technische Optik, Universität Stuttgart — [3]Nanoscribe GmbH, Eggenstein-Leopoldshafen

Complex three dimensional structures on the micrometer scale can be fabricated by focusing a femtosecond laser at 780 nm into a UV sensitive photoresist. The photoresist is polymerized via two-photon absorption at 390 nm in a small volume element around the laser focus, resulting in sub-micrometer resolution. By moving the focus through the photoresist arbitrary shapes can be produced.

Particularly the high resolution renders this direct laser writing technique suitable for the fabrication of high quality optical elements on the micrometer scale. However, many of the used materials exhibit shrinkage after polymerization, leading to deviations from the optical design and therefore reducing the imaging quality.

In this work we focus on the compensation of the shrinking behavior in order to achieve high shape fidelity. Furthermore, we present applications such as aspheric microlens arrays on CMOS sensors.

Q 53.4 Thu 11:15 K 0.016

Aberration compensation by complex beam shaping in direct laser writing implementing a SLM — •Mathias Hünecke, Haissam Hanafi, Jörg Imbrock, and Cornelia Denz — University of Münster, Institute of Applied Physics and Center for Nonlinear Science (CeNoS), Corrensstraße 2-4, 48149 Münster, Germany

Direct laser writing (DLW) is a powerful technique for creating complex refractive index structures in transparent materials. This technique paved the way to fabricate discrete waveguide arrays that allow tailored linear and nonlinear light propagation. Further applications of DLW are, for instance, diffractive optical elements or, in a visionary way, integrated optoelectronic devices.

The desired circular profile of waveguides is limited by spherical aberration and axial elongation caused by a refractive index mismatch when focusing from air into a high refracting material. These effects increase with larger writing depth, higher refractive index mismatches and higher numerical apertures. To overcome these limitations and enhance both, the variety of accessible materials and the writing depths, we apply complex beam shaping methods.

We will present an adaptive compensation of these aberrations by a spatial light modulator (SLM), which we implemented in a conventional DLW system. By applying a specific phase hologram, the initial wavefront is modified and reaches a spherical focus inside the writing volume. We demonstrate adaptive aberration correction in fused silica and nonlinear optical lithium niobate and characterize its performance for different parameters such as writing depth and numerical aperture.

Q 53.5 Thu 11:30 K 0.016

Birefrigent phasematching in an unpoled KTP waveguide as a source of pure infrared single photons — •Laura Padberg, Vahid Ansari, Matteo Santandrea, Christof Eigner, John M. Donohue, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Integrated pure single photon sources are a key component for quantum optical applications like quantum computation or quantum key distribution. Waveguides sources with tailored spatial modes are necessary for efficient coupling to optical fibres and integration into quantum networks.

We show our in-house fabrication of unpoled rubidium exchanged waveguides in potassium titanyl phosphate (KTP) and the birefringent characterisation of the generated parametric down conversion (PDC) state in our source. We demonstrate that our source design offers the possibility for asymmetric group velocity matching in the near-infrared telecommunication regime [1], which is a favourable condition for pure single photon generation. This makes it a perfect candidate for fibre-based networks and quantum protocols.

[1] arxiv.org/abs/1711.09678

Q 53.6 Thu 11:45 K 0.016

Ultrafast single photon detection on a photonic waveguide — Julian Muenzberg[2,4], Andreas Vetter[4,5], Wladick Hartmann[1,2,3], Fabian Beutel[1,2,3], •Simone Ferrari[1,2,3], Carsten Rockstuhl[4,5], and Wolfram Pernice[1,2,3] — [1]University of Münster, Institute of Physics, Germany — [2]University of Münster, CeNTech - Center for Nanotechnology, Germany — [3]University of Münster, Münster Nanofabrication Facility, Germany — [4]Karlsruhe Institut of Technology, Institute of Theoretical Solid State Physics, Germany — [5]Karlsruhe Institut of Technology, Institute of Nanotechnology, Germany

A key building block for quantum photonics is represented by integrated detectors with high efficiency and timing resolution [1]. For high bandwidth quantum communication ultrafast detection is also needed. We realized extremely short superconducting nanowire detectors onto silicon nanophotonic platform which, thanks to their reduced kinetic inductance, can provide an extremely high detection rate [2]. To enhance their efficiency, we embedded these detectors into a two-dimensional photonic crystal cavity obtaining efficient and fast detectors with sub-ns recovery time. [1] Science 318 (5856), 1567 (2007) [2] Nano Lett., 16 (11), 7085 (2016)

Q 53.7 Thu 12:00 K 0.016

Fine tuning of third harmonic phase-matching in tapered fibre via external gas pressure — •Jonas Hammer[1,2], Riccardo Pennetta[1], Philip St.J. Russell[1,2], and Nicolas Y. Joly[1,2] — [1]Max-Planck Institute for the Science of Light, Erlangen, Germany —

[2]University of Erlangen-Nuremberg, Erlangen, Germany

Micrometer-scale fibre tapers (FTs) are an interesting platform for nonlinear optics, since tight light confinement can provide very high effective nonlinearity. This allows the observation of nonlinear effects at moderate pump energies, provided the dispersion landscape is designed to satisfy the phase-matching (PM) conditions [1]. Here, we focus on the generation of third harmonic. For this process the conservation of photon momentum implies that $n(\omega_p) = n(3\omega_p)$, where ω_p is the pump frequency [2]. In waveguides the chromatic dispersion prevents intra-modal PM. The inter-modal PM conditions set strict constraints on the diameter of the FT, which are hard to fulfill during the fabrication procedure. Here, we fabricated a FT with a waist diameter of $0.68\mu m$. We obtained inter-modal PM between the HE_{11} mode in the IR and HE_{12} in mode in the visible. Surrounding the FT with argon gas permits the third-harmonic wavelength to be tuned by 0.12 nm/bar. Pressure-tuning greatly relaxes the fabrication tolerances for third harmonic generation in FT, which is extremely advantageous in systems with a fixed pump wavelength.

References

[1] T.A. Birks et al., Opt. Lett. (25), 1415 (2000).

[2] R.W. Boyd, Nonlinear Optics, 3rd ed. (Academic press, 2008).

Q 53.8 Thu 12:15 K 0.016

Twisted coreless photonic crystal fibre — •Gordon K. L. Wong, Ramin Beravat, Michael H. Frosz, Paul Roth, and Philip St.J. Russell — Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058 Erlangen, Germany

We report a new mechanism of light guidance, based on a continuously twisted photonic crystal fibre without any core structure. The permanent twist around the fibre axis was induced by spinning the fibre preform during the drawing process. Twisting the uniform periodic array of hollow channels creates a topological channel where light can be trapped. This unusual phenomenon arises from the quadratic increase in optical path length with radius, creating a potential well within which light is confined by photonic bandgap effects. The effective area of these orbital angular momentum carrying modes shrinks with increasing twist rate, so that by varying the twist rate along the fibre, it would be possible to create fibers whose mode-field diameter changes with axial position. Another advantage is the combination of a large mode area with anomalous dispersion at shorter wavelengths compared to conventional fibres. The ability of the fibre to transmit modes carrying orbital angular momentum and exhibit optical activity suggests that yet more applications will emerge.

Q 54: Nano-Optics (Single Quantum Emitters and Plasmonics)

Time: Thursday 10:30–12:45 Location: K 0.023

Q 54.1 Thu 10:30 K 0.023

An optical nanofiber-based interface for single molecules — •Hardy Schauffert, Sarah Skoff, David Papencordt, and Arno Rauschenbeutel — Technische Universität Wien

Integrated optical interfaces for quantum emitters are a prerequisite for implementing quantum networks. In this context, tapered optical fibers with a nanofiber waist recently received significant attention as an efficient means of light-matter interaction. Due to the subwavelength diameter of the waist, a large fraction of the light propagates outside of the fiber as an evanescent wave. An emitter brought close to the surface of the nanofiber strongly interacts with the guided light field. Here, we couple single organic dye molecules to the guided modes of an optical nanofiber. The molecules are embedded in a nanocrystal host that provides photostability and due to the resulting inhomogeneous broadening, a means to spectrally address single molecules. The molecules are optically excited and their fluorescence is detected solely via the nanofiber interface without the requirement of additional optical access. I will discuss our results, where we observed the emission of bandwidth limited single photons by individually adressable molecules into the nanofiber. Furthermore we show our first results of the effect of single molecules on the fiber guided light. These results show, that our approach is a possible candidate for a versatile, fiber integrated constituent for quantum hybrid systems.

Q 54.2 Thu 10:45 K 0.023

On-Chip Quantum Optics in 1D: Single Molecules Coupled via a Dielectric Nanoguide — •Dominik Rattenbacher[1], Alexey Shkarin[1], Pierre Türschmann[1], Jan Renger[1], Tobias Utikal[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light (MPL), Erlangen, Germany — [2]Friedrich-Alexander University (FAU) Erlangen-Nürnberg, Erlangen, Germany

One-dimensional subwavelength waveguides (nanoguides) promise efficient light-matter interactions between photons in the waveguide mode and individual emitters separated on length scales much longer than their transition wavelength [1,2]. We report on the coupling of organic dye molecules at low temperatures to the confined mode of a TiO_2-waveguide via the evanescent field and demonstrate external control on the resonance frequencies of the molecules via the DC Stark effect. This allows one to match the resonance frequencies of two emitters, thus controlling their coherent coupling via the nanoguide. In future, we want to boost our emitter-nanoguide coupling by the use of on-chip resonators [3]. This will enable us to build up a network of strongly coupled quantum emitters and study the emergence of polaritonic states [4].

[1] S. Faez et al., Phys. Rev. Lett. **113**, 213601 (2014)

[2] P. Türschmann et al., Nano Lett. **17**, 4941 (2017)

[3] N. Rotenberg et al.,Optics Express **25**, 5397, (2017).

[4] H. R. Haakh et al., Phys. Rev. A **94**, 053840 (2016).

Q 54.3 Thu 11:00 K 0.023

Coherent coupling of a single molecule to a scanning Fabry-Pérot microcavity — •Daqing Wang[1], Hrishikesh Kelkar[1], Diego Martin-Cano[1], Tobias Utikal[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nuremberg, D-91058 Erlangen, Germany

We report on the coherent coupling of a single organic molecule to a scannable, tunable and broadband microcavity. The cavity consists of a planar distributed Bragg reflector and a micromirror with a small radius of curvature of 5 μm fabricated with focused ion-beam milling and coated with silver or dielectric multilayers. By integrating a thin organic crystal in the microcavity at liquid helium temperature, we are able to coherently couple individual molecules to a single mode of the cavity. Our experimental and theoretical results show that a single molecule can block the cavity transmission nearly perfectly. We present a strong modification of the phase and photon statistics of a laser beam and demonstrate improvement of single-molecule stimulated emission compared to free-space coupling in a tight focus.

Q 54.4 Thu 11:15 K 0.023

Coherent interaction of light with a single molecule near a plasmonic nano-antenna — •Johannes Zirkelbach, Tobias Utikal, Stephan Götzinger, and Vahid Sandoghdar — Max Planck Institut für die Physik des Lichts, 91058 Erlangen, Deutschland

At cryogenic temperatures, single molecules in organic matrices are efficient quantum emitters. Using dedicated nanofabrication and combination of high-resolution spectroscopy with localization microscopy, we observed the radiative enhancement of the fluorescence of a single molecule in the vicinity of a plasmonic nanostructure. We demonstrate the modification of the molecule's excited state lifetime through Hanbury-Brown and Twiss measurements. Direct extinction measurements in reflection and transmission allow us to explore the change of linewidth in the zero-phonon-line and the coherent interaction among the incident laser beam, the molecular emission and the scattering from the gold nanostructure. We discuss the effect of spectral diffusion and dephasing for future experiments.

Q 54.5 Thu 11:30 K 0.023

Plasmonic enhancement at a liquid-solid interface — •Yazgan Tuna and Vahid Sandoghdar — Max-Planck-Institute for the Science of Light

Trapping and manipulation of small objects have been of great interest for a range of applications. Here we report on electrostatic trapping of charged nanoparticles between the aperture of a nanopipette and a glass substrate without the need for external potentials [1]. We employ our technique to the manipulation of a plasmonic nanoantenna in an aqueous solution in order to scan a trapped gold nanosphere in the near field of a single colloidal quantum dot embedded under the substrate surface. We demonstrate about 8-fold fluorescence enhancement over a lateral full width at half-maximum of about 45 nm [2]. We analyze our results with the outcome of numerical electromagnetic simulations under consideration of the electrostatic free energy in the trap. Our approach could find applications in a number of experiments, where plasmonic effects are employed at liquid-solid interfaces.

[1] Kim, J. T. et al. Nat. Commun. 5, 3380 (2014). [2] Y. Tuna et al. ACS Nano. 11, 7674 (2017).

Q 54.6 Thu 11:45 K 0.023

Coupling of quantum emitters to plasmonic nanostructures in functional devices built from DNA — •Steffen Both[1], Maximilian J. Urban[2,3], Klas Lindfors[4], Na Liu[2,3], and Thomas Weiss[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart — [2]Kirchhoff Institute for Physics, University of Heidelberg — [3]Max Planck Institute for Intelligent Systems, Stuttgart — [4]Department of Chemistry, University of Cologne

In recent years, DNA nanotechnology has emerged to a powerful platform that allows the realization of functional artificial devices on the nanoscale. Recently, we demonstrated a DNA based nanomachine that uses two gold nanocrystals as a gear and can perform a reversible sliding movement. The sliding displacement can be in situ monitored by tracking the fluorescence of two attached fluorophores, which exchange energy via Förster resonance energy transfer (FRET). Electromagnetic interaction with the plasmonic resonances of the gold nanocrystals strongly affects the fluorophores, resulting in a complex response of the system. We present a theoretical investigation of this interaction and discuss the underlying energy transfer mechanisms.

Q 54.7 Thu 12:00 K 0.023

Ultranarrow Nonlinear Resonances in Hybrid Fiber-Plasmon Cavities — •Qi Ai[1], Lili Gui[1], Domenico Paone[1], Bernd Metzger[1], Martin Mayer[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCOPE, University of Stuttgart, Germany — [2]Leibniz Institute of Polymer Research Dresden, Department of Physical Chemistry and Polymer Physics, Germany

We demonstrate substantial reduction of the LSPR linewidth of an Au nanorod by depositing it onto the surface of a tapered fiber. When the tapered diameter is reduced to about 1-3 **m, we observe signatures of strong coupling between the LSPR modes and the whispering gallery modes of the tapered fiber. This results in a very narrow hybrid plasmon-fiber resonance of the single Au nanorod, with a much higher quality factor Q (up to 300) when compared with that of an Au nanorod or an uncoated fiber with the same diameter. The strong coupling leads to a significant enhancement of the peak scattering intensity at the plasmon resonance. Second-harmonic generation is boosted to typically three orders of magnitude higher conversion efficiency in comparison to that from a single uncoupled Au nanorod. Moreover, the nonlinear resonance is ultranarrow (below 10 nm), benefitting from its fundamental mode with a high quality factor. An analytical anharmonic oscillator model gives good agreement with the experimentally observed wavelength-dependent nonlinear emission. In addition, giant multi-photon photo-luminescence up to 5th order has been observed.

Q 54.8 Thu 12:15 K 0.023

Nonlinear 3D chiral plasmonics — •Lili Gui, Mario Hentschel, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany

Optical activity is a general phenomenon in nature, as many biomolecules are chiral. Chiral plasmonics is highly interesting for biosensing applications since natural chiral substances can be mimicked and a gigantic chiroptical response can be obtained due to the superchiral near-field. Exploration of nonlinear chiroptical effects in chiral plasmonic nanostructures is even more desired since the nonlinear chiroptical effects might be orders of magnitude higher than their linear counterparts. Although diverse chiral plasmonic systems have been investigated, the underlying physical mechanism for nonlinear plasmonic chirality is far from being understood and further quantitative modelling is particularly missing.

Here we study the third-order chiroptical response of 3D chiral structures consisting of identical corner-stacked gold nanorods, the so-called plasmonic Born-Kuhn analog. We experimentally investigate the third-harmonic spectroscopy with both left- and right-handed fundamental light. Utilizing a coupled anharmonic oscillator model that includes phase retardation of the incoming fundamental and outgoing generated wave, we are able to retrieve the third-order chiroptical effects. This model is quite instructive for the efficient design of plasmonic chiral structures for giant nonlinear circular dichroism and might pave the way towards ultrasensitive nonlinear chiral sensing.

Q 54.9 Thu 12:30 K 0.023

Measuring Quantum Yield of Organic Dyes by Lifetime Modifications Using a Metal Ball — •Ersan Özelci[1,3], Ute Resch-Genger[2,3], and Oliver Benson[1,3] — [1]Humboldt-Universität zu Berlin — [2]Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin — [3]School of Analytical Sciences Adlershof (SALSA), Berlin

A key parameter for all fluorescence applications presents the photoluminescence quantum yield which can be determined by optical methods either relatively compared to a fluorescence quantum yield standard with known QY or absolutely with e.g., integrating sphere spectroscopy [1]. An interesting alternative, that can be even extended to single emitters, presents the so-called silver ball method which utilizes the modification of the spontaneous emission of dyes in the neighborhood of metallic surface [2,3].

In our experiment, the silver coated spherical ball is placed on PMMA coated glass substrate. Then, confocal fluorescence lifetime imaging (FLIM) microscope is performed using scanning piezo stage. FLIM maps with concentric rings centered with respect to the contact point of the sphere are obtained. The variation of the fluorescence lifetime as a function of the molecule to sphere distance are extracted from the FLIM map. We fitted the data to theoretical curves and derived the QY. We will discuss planned experiments towards an integration of our approach with microfluidics setups.

[1] C. Würth et al., Nat Protocols 2013.
[2] K.Drexhage et al, J.Lumin, 1-2, 693 (1970).
[3] Lunnemann et al, ACS Nano 2013, 5984-5992.

Q 55: Quantum Effects

Time: Thursday 10:30–12:30 Location: K 1.013

Group Report Q 55.1 Thu 10:30 K 1.013

Strong Coupling between Photons of Two Light Fields mediated by one Atom — •Nicolas Tolazzi, Christoph Hamsen, Bo Wang, Jonas Neumaier, Gang Li, Alejandro González-Tudela, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

The key ingredient for many applications in quantum information processing is the controlled interaction between individual photons. In classical nonlinear optical media, typical interaction strengths are negligible at the level of individual quanta. However a significant interaction between single photons can be reached in single atom cavity quantum electrodynamics. Despite this paradigm's success in quantum nonlinear optics with multiple photons in one mode, engineering a system with direct nonlinear coupling between photons in two different modes is still an outstanding challenge. Here, we discuss how two optical cavity fields can be brought to interaction using a single four-level atom. While each field by itself is transmitted unaltered, already a single photon in one mode suppresses the transmission of photons in the other mode. As experimental proof we show strong anti correlations between the photons in the different light fields. Extending this system to the dispersive regime for one of the cavity modes would allow for sensing the exact number of photons in that mode without destroying them, leading to nondestructive counting of photons and heralded n-photon sources. We will present ideas, experimental results and perspectives towards the realization of such effects.

Q 55.2 Thu 11:00 K 1.013

Geometric phase in a quantum heat engine prototype — Sajal Kumar Giri and •Himangshu Prabal Goswami — Max-Planck-

Institute for the Physics of Complex Systems, Dresden

We theoretically study a 4-level quantum system coupled to two thermal baths and a unimodal cavity which serves as a quantum heat engine prototype. By periodically modulating the temperature of the thermal baths in an adiabatic fashion, one can realize geometric or Pancharatnam-Berry phaselike (PBp) contributions identifiable from a full counting statistical method. Through the PBp contributions, the effect of quantum coherences in optimizing the total flux can be nullified. The PBp effects cause the universality in the expansion coefficient (1/2) and the universal bounds on the efficiency at maximum power as well as the Gallvotti-Cohen type of symmetry to be violated. We further observe a seeming inapplicability in the use of a standard large deviation technique to evaluate the cavity photon-flux probability distribution function.

Q 55.3 Thu 11:15 K 1.013

Multi-Photon correlations in an one-dimensional waveguide by light-matter interaction — •Kevin Kleinbeck, Jan Kumlin, and Hans Peter Büchler — University of Stuttgart, Institute for theoretical Physics 3, Stuttgart, Germany

We consider the scattering of photons at artificial atoms in one-dimensional, chiral waveguide systems and study the effective photon-photon interaction mediated by this medium. For the single atom system, we derive a generating functional for the outgoing wave function of any arbitrary multi-photon input state. Using this solution, we study the emergence of three-body correlations under the waveguide dynamics. We show, that even though the system only allows for two-body interactions, the three-body correlation function has contributions both from two-body and purely three-body effects.

In addition, we analytically prove the existence of universal many-body bound states in this model. We find numerical evidence that these bound state contributions become more important with increasing width of the initial wave function.

Q 55.4 Thu 11:30 K 1.013

Few-photon nonlinear optics using chirally-coupled two-level atoms — •Sahand Mahmoodian[1], Mantas Čepulkovskis[2], Sumanta Das[2], Peter Lodahl[2], Klemens Hammerer[1], and Anders Sørensen[2] — [1]Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark

Waveguide quantum electrodynamics studies the interaction between a quantum emitter coupled to a 1D photonic reservoir. It has been recently demonstrated that when quantum emitters couple to tightly-confined optical waveguide modes the light–matter interaction can become chiral leading to directional spontaneous emission and direction-dependent scattering of light. In this talk I discuss using a chain of N chirally-coupled two-level emitters driven by a resonant weak to mediate strong photon–photon interactions. By solving for the one- and two-photon dynamics analytically, we show that the physics of this system is governed by the interplay of nonlinear interactions and photon losses due to coupling to an external reservoir. For large optical depths the system evolves into a state that has a strongly bunched second-order correlation function and the output power exhibits a sub-exponential (inverse polynomial) scaling with N. By using an asymptotic expansion we describe these effects analytically. These dynamics can be demonstrated in state-of-the-art tapered fiber setups with trapped atoms.

Q 55.5 Thu 11:45 K 1.013

Localization control of few-photon states in parity-symmetric photonic molecules — •Christopher D B Bentley[1], Alan Celestino[1], Alejandro M Yacomotti[2], Ramy El-Ganainy[3], and Alexander Eisfeld[1] — [1]Max Planck Institute for the Physics of Complex Systems, Noethnitzer Strasse 38, 01187 Dresden, Germany — [2]Laboratoire de Photonique et de Nanostructures (CNRS UPR 20), Route de Nozay, Marcoussis 91460, France — [3]Department of Physics and Henes Center for Quantum Phenomena, Michigan Technological University, Houghton, MI 49931, USA

Spontaneous symmetry breaking (SSB) has been demonstrated approaching the quantum regime (with around 150 photons) using optically pumped, parity-symmetric photonic molecules [1]. The occurrence of SSB in the few-photon regime is a topic of active investigation. In this regime there are significant quantum fluctuations due to environmental couplings. We consider a system of two coupled, identical, optically-driven cavities, as in [1]. In this system, quantum fluctuations lead to transient population imbalance between the cavities, i.e. one cavity has higher population (mean photon number) than the other. No cavity is preferred: on average, there is no population imbalance. However, we demonstrate using feedback that one can control the population imbalance in this system without breaking the mirror-symmetry of the cavity driving. By time-dependent modulation of the amplitude of the mirror-symmetric driving, we select a cavity to have higher population on average.

[1] P. Hamel et al. 2015, Nature Photonics 9 (311)

Q 55.6 Thu 12:00 K 1.013

Linking ab-initio theory and phenomenological models of cavity QED — •Dominik Lentrodt, Kilian P. Heeg, Christoph H. Keitel, and Jörg Evers — MPI für Kernphysik, Heidelberg

Historically, there has been a gap in cavity QED between ab-initio theory and a class of phenomenological models based on the input-output formalism. These models have been important in understanding empirical results in the strong coupling regime of cavity QED, since they allow to reduce the dynamics of the atom-cavity system to an effective description in terms of few cavity modes. However despite their success, a derivation of the underlying Gardiner-Collett Hamiltonian from ab-initio quantisation has been elusive and its applicability in low-Q cavities has been debated [1].

Here we present a method to construct a family of Gardiner-Collett Hamiltonians from canonical quantisation of the dielectric Maxwell equations. We explicitly show the relation between classical scattering theory and the input-output formalism, revealing the necessity of a previously unknown background scattering factor. When an atom is added to the cavity, our formalism naturally yields an effective few-mode description of the system as a non-perturbative approximation scheme, in the same way as phenomenological models.

We expect our technique to find applications in the emerging field of x-ray cavity QED with Mössbauer nuclei, where low-Q cavities are in use and previously unknown phase shifts have been observed [2].

[1] S M Dutra & G Nienhuis (2000). Journal of Optics B, 2, 584. [2] Heeg, K. P. & Evers, J. (2015). Phys. Rev. A, 91, 063803.

Q 55.7 Thu 12:15 K 1.013

Generation of an X-ray echo from a nuclear resonance under magnetic field rotations — •Jonas Gunst[1], Chia-Jung Yeh[2], Wen-Te Liao[2], and Adriana Pálffy[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Department of Physics, National Central University, Taoyuan City, Taiwan

While Moore's law predicts the fast evolution of miniaturization, for future photonic devices the optical diffraction limit will emerge as bottleneck. Going to shorter wavelengths, e.g. x-ray photons, would drastically reduce this limitation and opens new possibilities for information science. However, versatile control of the basic properties of such photons is the key requirement for short wavelength photonic information carriers.

Nuclear forward scattering, as it occurs with ^{57}Fe Mössbauer nuclei, presents a great basis for exerting coherent control on x-ray photons. The nuclear response can be controlled by subjecting the sample to a hyperfine magnetic field and to fast rotations of the latter. Within such a setup the realizability of logical operations on polarization-encoded x-rays has already been demonstrated [1]. Inspired by the control of broadband quantum excitations using gradient photon echoes [2], we show here that such an echo can be generated in the x-ray regime by employing a setup consisting of multiple ^{57}Fe targets controlled via external magnetic field rotations.

[1] J. Gunst, C. H. Keitel and A. Pálffy, Sci. Rep. **6**, 25136 (2016).

[2] W. Liao, C. H. Keitel, and A. Pálffy, Phys. Rev. Lett. **113**, 123602 (2014).

Q 56: Quantum Information (Coherence and Entanglement)

Time: Thursday 10:30–12:30 Location: K 1.019

Q 56.1 Thu 10:30 K 1.019

Structure of the resource theory of quantum coherence —

•Alexander Streltsov[1], Swapan Rana[2], Paul Boes[3], and Jens Eisert[3] — [1]Gdansk University of Technology, Poland — [2]ICFO, Barcelona, Spain — [3]Freie Universität Berlin, Germany

Quantum coherence is an essential feature of quantum mechanics which is responsible for the departure between classical and quantum world. The recently established resource theory of quantum coherence studies possible quantum technological applications of quantum coherence, and limitations which arise if one is lacking the ability to establish superpositions. An important open problem in this context is a simple characterization for incoherent operations, constituted by all possible transformations allowed within the resource theory of coherence. Here, we contribute to such a characterization by proving several upper bounds on the maximum number of incoherent Kraus operators in a general incoherent operation. For a single qubit, we show that the number of incoherent Kraus operators is not more than 5, and it remains an open question if this number can be reduced to 4. The presented results are also relevant for quantum thermodynamics, as we demonstrate by introducing the class of Gibbs-preserving strictly incoherent operations, and solving the corresponding mixed-state conversion problem for a single qubit.

See also A. Streltsov, S. Rana, P. Boes, and J. Eisert,
Phys. Rev. Lett. **119**, 140402 (2017).

Q 56.2 Thu 10:45 K 1.019

Coherence Fluctuation Relations —

•Benjamin Morris, Bartosz Regula, and Gerardo Adesso — School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom.

Following recent work on the role of resource theories in the emergence of fluctuation relations, we have identified coherence fluctuation theorems during a pure state transformation. These results have allowed a formal identification of relations analogues to the Jarzynski and Crooks relations within the resource theory of quantum coherence. This has been achieved by considering reversible pure state manipulations under strictly incoherent operations supplemented by the use of a coherence battery, i.e., a storage device whose degree of coherence is allowed to fluctuate while mediating the transformation. The necessity of a battery to mediate the transformation allows a comparison of coherent transformations to classical thermodynamic transformations where the amount of fluctuating work is generally described via an intermediary system. Our work on coherence provides another example of a resource theory (in addition to athermality and entanglement) where a connection is established between majorization theory and fluctuation relations. This is hoped to provide further insight into the general structure of battery assisted quantum resource theories, and more specifically in the interplay between quantum coherence and quantum thermodynamics.

Q 56.3 Thu 11:00 K 1.019

A resource theory of quantum process coherence —

•Felix Bischof, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

The coherent superposition of states is one of the fundamental features of quantum mechanics that distinguish it from the classical realm. In particular, virtually any quantum information protocol requires coherence in order to achieve a quantum advantage. Recently, coherence has received renewed attention in the context of a resource theory [1], in which coherence is a valuable resource that, due to restrictions on operations, can only be processed but not generated. In this context, coherence-free states, coherence-nonincreasing operations, and coherence measures are defined with respect to a fixed quantum state basis. We investigate a generalization of the concept of coherence with respect to general quantum processes. In particular, we argue how the ingredients of a generalized resource theory of coherence can be obtained.

[1] A. Streltsov, G. Adesso, and M. B. Plenio, Rev. Mod. Phys. 89, 041003 (2017)

Q 56.4 Thu 11:15 K 1.019

Distribution of coherence in multipartite systems —

•Tristan Kraft and Marco Piani — University of Strathclyde, Glasgow G4 0NG, United Kingdom

We study the distribution of quantum coherence in multipartite systems, by comparing the global coherence to the coherence of the marginals. First we introduce a quantifier in terms of the relative entropy of coherence to measure how much the global state is coherent compared to its marginals. We evaluate this quantifier for maximally entangled two-qubit states. Interestingly, we find that there are coherent states that are locally incoherent, but the coherence can be completely transferred to its marginals by decorrelating the system using incoherent unitary operations. States for which this is impossible are genuinely multipartite coherent. We provide necessary and sufficient conditions for pure states to have zero genuine multipartite coherence. Furthermore, we calculate the amount of genuine multipartite coherence for two-qubit pure states.

Q 56.5 Thu 11:30 K 1.019

Subcycle tracing of ultrabroadband squeezed light transients from nonlinear crystals —

•Matthias Kizmann[1], Thiago Lucena de M. Guedes[1], Philipp Sulzer[1], Denis V. Seletskiy[2], Andrey S. Moskalenko[1], Alfred Leitenstorfer[1], and Guido Burkard[1] — [1]Department of Physics and Center for Applied Photonics, University of Konstanz, Germany — [2]Department of Engineering Physics, Polytechnique Montréal, C-6079 Montréal, Canada

The electro-optic effect can be used to sample the vacuum fluctuations of the electric field [1]. Moreover, this technique provides a way to study the dynamics of the variance of the probed field with subcycle resolution. Recently, this was shown by sampling the relative differential noise patterns of a transient squeezed vacuum state generated in a thin nonlinear crystal [2]. We demonstrate theoretically that the quantum dynamics of ultrabroadband squeezed light transients generated in thin nonlinear crystals can be determined for certain characteristic shapes of the driving few-cycle coherent pulses. The squeezing and anti-squeezing can be interpreted as a result of a change in the local run of time, induced by the driving pulse. Furthermore, we predict that the conventionally observed asymmetry between squeezing and more pronounced anti-squeezing in the temporal noise traces, resulting from the product character of Heisenberg's uncertainty relation, can be reversed with specific driving pulses. We argue that this phenomenon can be realized under realistic conditions of the state-of-art experiments.

[1] C. Riek et al., Science 350, 420 (2015).
[2] C. Riek et al., Nature 541, 376 (2017).

Q 56.6 Thu 11:45 K 1.019

Characterizing Multipartite Entanglement —

•Jan Sperling and Ian Walmsley — Clarendon Laboratory, University of Oxford, United Kingdom

Quantum correlations between multiple degrees of freedom or particles play a fundamental role for quantum communication protocols. In this contribution, we describe how complex structures of multipartite entanglement can be certified using nonlinear eigenvalue equations [1]. This allows for the in-depth analysis of entanglement between many parties and the formulation of measurable entanglement criteria. Recent experimental applications to frequency combs underline the capabilities of our method [2]. Finally, the entangling dynamics of interacting systems is uncovered by nonlinear Schroedinger-type equations [3]. Consequently, we present a unified framework to study quantum entanglement in stationary and time-dependent, multipartite systems.

[1] J. Sperling and W. Vogel, Phys. Rev. Lett. 111, 110503 (2013). [2] S. Gerke, J. Sperling, W. Vogel, Y. Cai, J. Roslund, N. Treps, and C. Fabre, Phys. Rev. Lett. 114, 050501 (2015). [3] J. Sperling and I. A. Walmsley, Phys. Rev. Lett. 119, 170401 (2017).

Q 56.7 Thu 12:00 K 1.019

Characterizing entanglement with scrambled data —

•Timo Simnacher[1], Nikolai Wyderka[1], Gael Sentís[1], Rene Schwonnek[2], and Otfried Gühne[1] — [1]Universität Siegen, Siegen, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

In an ordinary entanglement detection scenario, the possible measurements and the corresponding data are given. In contrast to device-independent scenarios, where the measurements are not characterized but the data have a clear interpretation, we consider the case where the measurements are characterized but the data is scrambled. That means, the assignment of outcomes to the corresponding probabilities is unknown.

As an example, we investigate the two-qubit scenario with local measurements of $\sigma_x \otimes \sigma_x$ and $\sigma_z \otimes \sigma_z$. In this setting, we first find a class of entanglement witnesses invariant under permutation of probabilities and hence, it is indeed possible to detect entanglement even when the data is scrambled. Second, since entropies are naturally invariant under scrambling, it seems reasonable to consider entropic uncertainty relations to detect entanglement. Numerical and analytic results indicate that Shannon entropy is not suitable in this scenario, however, using Tsallis entropy $H_q(p_i) = \frac{1}{q-1}(1 - \sum_i p_i^q)$ is a promising approach for some q.

Q 56.8 Thu 12:15 K 1.019

Unitary designs for reference-frame independent entanglement detection — •Andreas Ketterer, Nikolai Wyderka, and Otfried Gühne — Universität Siegen, Siegen, Germany

The trustworthy detection of multipartite entanglement usually requires a number judiciously chosen local quantum measurements which are aligned with respect to a previously shared common reference frame. If such a reference frame is not available one has to develop alternative detection strategies which do not rely on a specific choice of the local measurement bases. One possibility in this direction is to perform a number of local measurements with settings distributed uniformly at random. Using such a statistical treatment we show that one can make use of quantum unitary designs to derive reference frame independent multi-qubit entanglement criteria based on the first six moments of the randomly measured expectation values. We illustrate our method in the case of a bipartite system where it allows for a characterization of all entangled Bell diagonal states. Subsequently, we move to the more involved multipartite scenario and show how to detect multi-qubit entanglement from two-body correlations.

Q 57: Ultracold Atoms I (joint session Q/A)

Time: Thursday 10:30–12:15 Location: K 1.022

Q 57.1 Thu 10:30 K 1.022

Multi-mode double-bright EIT cooling (theory) — Nils Scharnhorst[1,2], •Javier Cerrillo[3], Johannes Kramer[1], Ian D. Leroux[1], Jannes B. Wübbena[1], Alex Retzker[4], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Institut für Theoretische Physik, Technische Universität Berlin, 10623 Berlin, Germany — [4]Racah Institute of Physics, Hebrew University of Jerusalem, 91904 Jerusalem, Israel

We developed a multi-mode ground state cooling technique based on electromagnetically-induced transparency (EIT) [1]. By involving an additional ground and excited state, two individually adjustable bright states together with a dark state are created. While the dark state suppresses carrier scattering, the two bright states are brought into resonance with spectrally separated motional red sidebands. The approach is scalable to more than two bright states and several dark states by introducing additional laser couplings. For large laser intensities, the Lamb-Dicke theory becomes unsuitable and a description based in a generalized fluctuation-dissipation theorem for non-linear response [2] is presented.

[1] Scharnhorst et al., arXiv:1711.00738, arXiv:1711.00732, (2017).
[2] Cerrillo et al., PRB 94, 214308 (2016).

Q 57.2 Thu 10:45 K 1.022

Multi-mode double-bright EIT cooling (Experiment) — •Nils Scharnhost[1,2], Javier Cerrillo[3], Johannes Kramer[1], Ian D. Leroux[1], Jannes B. Wübbena[1], Alex Retzker[4], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Institut für Theoretische Physik, Technische Universität Berlin, 10623 Berlin, Germany — [4]Racah Institute of Physics, Hebrew University of Jerusalem, 91904 Jerusalem, Israel

Ground-state cooling (GSC) of ions and atoms is an essential prerequisite for many experiments in quantum optics, e.g. atomic clocks. Sideband cooling and cooling via electromagnetically induced transparency (EIT) are common techniques to achieve GSC. Due to their narrow cooling resonance, both techniques restrict cooling to a narrow frequency range. The desire to scale up the number of ions in quantum systems and to control all relevant (motional) degrees of freedom in such large atomic ensembles demands for novel cooling approaches, such as the capability to simultaneously cool several motional modes.

We developed double-bright EIT (D-EIT) cooling [1] as a novel scalable approach to standard EIT cooling by extending its level scheme by one additional ground and one excited state. D-EIT allows simultaneous GSC of modes around two separated frequencies and we experimentally demonstrate for the first time GSC of all three motional degrees of freedom of a trapped ion within a single, short cooling pulse.

[1] Scharnhorst et al., arXiv: 1711.00732v2 (2017)

Q 57.3 Thu 11:00 K 1.022

Ground state cooling of atoms 300 nm away from a hot surface — •Yijian Meng, Alexandre Dareau, Philipp Schneeweiss, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

Cold atoms coupled to light guided in nanophotonic structures constitute a powerful research platform, e.g., for probing surface forces, the study of light-induced self-organization, as well as quantum networking. The strong spatial confinement of the optical trapping fields in nanophotonic systems gives rise to significant fictitious magnetic field gradients. These can be used to perform degenerate Raman cooling (DRC), which has been pioneered in optical lattices [1].

Here, we implement DRC of atoms in a nanofiber-based optical trap [2]. Remarkably, this scheme only requires a single fiber-guided light field, which provides three-dimensional cooling. We show that continuously applying such cooling extends the lifetime of atoms in the trap by one order of magnitude. Using fluorescence spectroscopy [3], we precisely measure the temperature of the atoms. We find that they can be cooled close to the motional ground state despite the atoms being less than 300 nm away from the hot fiber surface. This achievement sets an excellent starting point for further experiments, for example, the investigation of heat transfer at the nanoscale using quantum probes.

[1] S. E. Hamann et al., Phys. Rev. Lett. 80, 4149 (1998).
[2] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010).
[3] P. S. Jessen et al., Phys. Rev. Lett. 39, 49 (1992).

Q 57.4 Thu 11:15 K 1.022

Radio-frequency sideband cooling and sympathetic cooling of trapped ions in a static magnetic field gradient — Theeraphot Sriarunothai[1], •Gouri Shankar Giri[1], Sabine Wölk[1,2], and Christof Wunderlich[1] — [1]Department Physik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany — [2]Institute for Theoretical Physics, University of Innsbruck, Technikerstraße 21a, 6020 Innsbruck, Austria

We report a detailed investigation on near-ground state cooling of one and two trapped atomic ions [1]. We introduce a simple RF sideband cooling method for confined atoms and ions, using RF radiation applied to bare ionic states in a static magnetic field gradient, and demonstrate its application to ions confined at secular trap frequencies, $\omega_z \approx 2\pi \times 117$kHz. For a single ^{171}Yb$^+$ ion, the sideband cooling cycle reduces the average phonon number, $\langle n \rangle$ from the Doppler limit to $\langle n \rangle = 0.30(12)$. This is in agreement with the theoretically estimated lowest achievable phonon number in this experiment. We extend this method of RF sideband cooling to a system of two ^{171}Yb$^+$ ions, resulting in a phonon number of $\langle n \rangle = 1.1(7)$ in the center-of-mass mode. Furthermore, we demonstrate the first realisation of sympathetic RF sideband cooling of an ion crystal consisting of two individually addressable identical isotopes of the same species.

[1] Th. Sriarunothai et al., arXiv: 1710.09241 (2017)

Q 57.5 Thu 11:30 K 1.022

Synchronization-assisted cooling of atomic ensembles —

•Simon B. Jäger[1], Minghui Xu[2,3], Stefan Schütz[4], John Cooper[2,3], Murray Holland[2,3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]JILA, National Institute of Standards and Technology and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA — [3]Center for Theory of Quantum Matter, University of Colorado, Boulder, Colorado 80309, USA — [4]icFRC, IPCMS (UMR 7504), ISIS (UMR 7006), Université de Strasbourg and CNRS, 67000 Strasbourg, France

We analyze the dynamics leading to radiative cooling of an atomic ensemble inside an optical cavity when the atomic dipolar transitions are incoherently pumped. Our study is performed in the regime where the cavity decay is the largest rate in the system. Using a semiclassical approximation we identify three stages of cooling. At first hot atoms are cooled by the cavity friction forces. After this stage, the atoms' center-of-mass motion is further cooled by the coupling to the internal degrees of freedom while the dipoles synchronize. In the latest stage dipole-dipole correlations are stationary and the center-of-mass motion is determined by the interplay between friction and dispersive forces due to the coupling with the collective dipole. For this final stage we derive a mean-field model that is valid on a timescale where particle-particle correlations build up slowly. On this timescale we observe that the system can reach momentum widths below the recoil limit. Beside this we find limit cycles and chaotic dynamics.

Q 57.6 Thu 11:45 K 1.022

Dissipative cooling of quasi-condensate excitations — •Carsten Henkel[1] and Isabelle Bouchoule[2] — [1]Universität Potsdam — [2]Institut d'Optique, Palaiseau

The elementary excitations of a Bose condensate are described by the celebrated Bogoliubov dispersion. Their spectrum is discrete for a trapped system. We discuss the theory of these excitations in experiments where atoms leave the trap in a controlled way. One observes a stationary non-equilibrium situation where temperature measurements give different results, either from the density profile or from density fluctuations [1]. We develop a simple stochastic theory based on quantum projection noise and find that the limiting temperature is slightly below the chemical potential. The calculations need accurate Bogoliubov mode functions that interpolate smoothly between the dense (Thomas-Fermi) region and the low-density wings [2, 3], a region where mean-field theories fail [4, 5].

[1] A. Johnson, S. Szigeti, M. Schemmer, and I. Bouchoule, Phys. Rev. A 96 (2017) 013623
[2] A. L. Fetter and D. L. Feder, Phys. Rev. A 58 (1998) 3185
[3] A. Diallo and C. Henkel, J. Phys. B 48 (2015) 165302
[4] L. Pitaevskii and S. Stringari, Phys. Rev. Lett. 81 (1998) 4541
[5] C. Henkel, T.-O. Sauer, and N. P. Proukakis, J. Phys. B 50 (2017) 114002

Q 57.7 Thu 12:00 K 1.022

Semiclassical Laser Cooling in Standing Wave Configurations — •Thorsten Haase and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, Germany

Laser cooling is a widely used technique in experiments in quantum optics and quantum information science. For most purposes of cooling above the Doppler limit laser fields are used which can be modelled by plane running waves. In this regime, the interaction between the radiation field and particles, modelled by two-level systems, is well explained by the semiclassical theory of Doppler cooling. Standing waves exhibit a different behaviour with analogies to blue detuned laser cooling at higher intensities [Ci92]. We present a semiclassical model for the interaction of a two-level system with arbitrary field modes, which includes standing and strongly focused waves. Our model exactly reproduces the theory of Doppler cooling for running plane waves. Additionally, it gives rise to different cooling properties inside standing laser fields. Our results are consistent with a special case investigated in [Ci92]. We simulate the interaction of a trapped two-level ion in the particular field configuration relevant for the 4Pi-Pac experiment in Erlangen [Al17], where the ion is trapped around the focus of a parabolic mirror to achieve almost perfect atom-photon coupling.

[Ci92] Cirac et. al, Phys. Rev. A, Vol. 46, No. 5, Sep 1992, 2668-2681 [Al17] Alber et. al, J. Europ. Opt. Soc. Rap. Public. 13, 14 (2017)

Q 58: Precision Measurements and Metrology (Gravity and Miscellaneous) (joint session Q/A)

Time: Thursday 10:30–12:00 Location: K 2.013

Q 58.1 Thu 10:30 K 2.013

A high-flux BEC source for the transportable Quantum Gravimeter QG-1 — •Jonas Matthias, Nina Grove, Maral Sahelgozin, Jan Philipp Barbey, Sven Abend, Waldemar Herr, and Ernst M. Rasel — Inst. f. Quantenoptik, LU Hannover

Absolute inertial sensors based on atom interferometry will benefit in two ways from using Bose-Einstein condensates (BEC). First, their low expansion rate reduces the leading order systematic uncertainties of current generation sensors. Second, the per-shot sensitivity will be increased by a higher interferometer contrast and by implementing higher-order Bragg diffraction compared to Raman diffraction used with thermal ensembles. However, formerly the application of BECs was hindered by the size and repition rate of typical BEC experiments, which usually fill a laboratory and have a repetition rate on the order of several ten seconds.

These limitations have been overcome by atom-chip-based BEC sources, which allow compact apparatuses and achieve a high flux at the same time. The source for the transportable Quantum Gravimeter QG-1 consists of a $2D^+$ MOT and a mirror MOT on a three-layer atom chip as published by Rudolph et al, 2015. The atoms will be evaporatively cooled to quantum degeneracy in a magnetic trap and released from the trap for atom interferometry in free fall. In this talk we will present the current progress on atom cooling and Bose-Einstein condensation.

This work is supported by the Deutsche Forschungsgemeinschaft (DFG) as part of project A01 within the SFB 1128 geo-Q.

Q 58.2 Thu 10:45 K 2.013

Pre-stabilized laser system for future gravitational-wave detectors at a wavelength of 1550nm — •Fabian Thies, Nico Koper, and Benno Willke — Max Planck Institute for Gravitational Physics, Hannover, Germany

To reduce thermal noise in future gravitational-wave detectors(GWDs)[1] and in updated current detectors[2] the use of cryogenic test masses is proposed. Silicon is a promising material for these test masses, because of its high mechanical quality factor and the good thermal conductivity at cryogenic temperatures. The use of silicon requires a laser source at a wavelength of 1550nm or longer.

Currently commercial available laser systems do not fulfill the demanding requirements concerning the laser power, frequency and intensity noise and the spatial beam profile of future GWDs.

We will use a low noise laser at the wavelength of 1550nm as a seed for erbium-ytterbium fiber amplifiers, to get into the range of the proposed laser power levels. To reach the demanded noise levels active stabilizations are necessary in such a laser system for GWDs.

Here we present the results of the characterization of several possible seed lasers and of a fiber ring cavity as an in-fiber frequency sensor.

[1]ET Science Team, ET conceptual design document ET-0106C-10, http://www.et-gw.eu/index.php/etdsdocument
[2]LIGO Scientic Collaboration, Instrument Science White Paper, https://dcc.ligo.org/public/0113/T1400316/004/T1400316-v5.pdf

Q 58.3 Thu 11:00 K 2.013

Sensor noise measurements for an improved active seismic isolation of the AEI 10m-Prototype — •Robin Kirchhoff — Albert-Einstein / Max-Planck Institut für Gravitationsphysik Hannover, Callinstraße 38, 30167 Hannover

Large scale, ground based interferometric gravitational wave detectors use a combination of passive isolation and active control loops to reduce the coupling of seismic motion into the Michelson interferometer. The active isolation is limited by the self-noise of the in-loop sensors and a precise characterization of this noise is needed to optimize the control loops. In the Albert-Einstein-Institute in Hannover, the Sub-SQL (standard quantum limit) interferometer is under construction, which

is a 10 m Michelson interferometer designed to be limited by quantum noise for prototyping techniques to surpass the SQL. To reach the quantum noise limit, all classical and technical noise sources, including seismic noise, must be suppressed below quantum noise levels. The seismic attenuation system (AEI-SAS) provides the required seismic pre-isolation of an optical platform using both passive and active techniques. Several huddle tests were performed using these seismically isolated platforms to precisely measure the noise of different inertial sensors and their amplifier electronics. The initially installed Sercel L-22D geophones were measured to have a higher self-noise compared to Sercel L-4C geophones. The geophones were therefore exchanged and the resulting improvement of the active isolation performance of the AEI-SAS was verified.

Q 58.4 Thu 11:15 K 2.013

Fabrication Process Control of Wire Grid Polarizers for the Deep Ultraviolet- by Transmission Spectroscopy in the Visible Spectral Range — •Walter Dickmann[1], Thomas Siefke[2], Johannes Dickmann[3], Carol Bibiana Rojas Hurtado[3], and Stefanie Kroker[1,2] — [1]Technische Universität Braunschweig, LENA Laboratory for Emerging Nanometrology — [2]Friedrich-Schiller-Universität Jena, Institute of Applied Physics — [3]Physikalisch-Technische Bundesanstalt Braunschweig

Wire grid polarizers (WGPs) are periodic nano-optical metasurfaces which act as polarizing elements. In the deep ultraviolet (DUV) region the performance of metallic WGPs is poor whereas wide bandgap semiconductors are promising materials for this spectral range. RCWA calculations provide extinction ratios (ERs) of up to 10^4. However, so far fabricated titanium dioxide WGPs achieved only ERs which are almost two orders of magnitude smaller than the simulated values. This is mainly due to surface roughness and deterministic structural deviations resulting from the fabrication process and approaching the size range of the structural features for short application wavelengths. In this contribution we present a method to characterize deterministic structural deviations of DUV polarizers at the nanometer scale by transmission spectroscopy in the visible spectral range. The achieved results lay the foundation for an in situ fabrication process control.

This research is supported by the DFG within research training group 'Metrology for Complex Nanosystems' (GrK 1952/1) and within project 'PolEx' (KR4768/1-1).

Q 58.5 Thu 11:30 K 2.013

Thickness uniformity measurements of crystalline AlGaAs mirror coatings — •Philip Koch — MPI für Gravitationsphysik, Hannover, Deutschland

Beside quantum noise, the sensitivity of the current generation of gravitational wave detectors is limited by coating Brownian noise of the interferometer mirrors. This arises from thermal fluctuations of the molecules in the coating itself. Coating Brownian noise is dependent on the mechanical loss angle of the coating materials. AlGaAs mirror coatings are crystalline dielectric coatings which have higher Q factors (lower loss) and thus a ten-fold reduction of coating Brownian noise compared to the commonly used amorphous silica-tantala coatings. A homogenous surface figure is needed in the high precision interferometry to avoid optical losses. A method to measure the surface homogeneity of mirror coatings will be presented with an accuracy of below 0.05 nm. This method was used to measure a 0.5 nm RMS thickness homogeneity across a 5 cm diameter AlGaAs coating provided by Crystalline Mirror Solutions.

Q 58.6 Thu 11:45 K 2.013

Feasibility and Possibility of Testing Non-Classical Features of Gravity in a Double-slit-Type Experiment — •Sahar Sahebdivan — Atominstitut, TU Wien, Stadionallee 2, 1020 Wien

In this presentation, we are exploring the feasibility of observing non-classical features of gravity in a low-energy regime in a quantum optics experiment.

If gravity has an underlying quantum nature, it should hold the most fundamental quantum characteristics such as superposition principle and entanglement. Despite the weakness of gravity, in principle there is a chance, to observe such a quantum signature of the gravity by exploiting the quantum optical techniques, without direct observation of graviton.

We are investigating a new dynamical scheme called, gravitational quantum regime, in which the source of gravity is a quantum particle, and its centre of mass is subject to the spatial superposition. In a Gedankenexperiment, a test particle is gravitationally interacting with a quantum nanoparticle in a double-slit setup. Possible entanglement or superposition of the fields is investigated.

We are looking for the corresponding deviation of the classical description of gravity despite being far from Planck scale. Any experimental interrogation which reveals that gravitational field obeys the quantum superposition principle would be the first recognition of quantumness of gravity. This study will show how feasible it is to search for a non-classical feature of gravity in such regime of motion.

Q 59: Quantum Gases (Bosons) VI

Time: Thursday 10:30–12:45 Location: K 2.020

Q 59.1 Thu 10:30 K 2.020

Dynamical signatures of $\mathbb{Z}_2$ gauge invariance on a single plaquette — •Christian Schweizer[1], Fabian Grusdt[2], Moritz Berngruber[1], Michael Lohse[1], Monika Aidelsburger[1], Luca Barbiero[3], Nathan Goldmann[3], Eugene Demler[2], and Immanuel Bloch[1] — [1]LMU München & MPQ Garching — [2]Harvard University, Massachsetts, USA — [3]Université libre de Bruxelles, Belgium

Synthetic magnetic and electric fields for ultracold neutral atoms have been implemented in various setups with dynamical control over the systems' parameters. However, the realized fields are purely classical and there exists no back-action of the particles on these fields. Here, we present a minimal example that exhibits fully coherent quantum dynamics for the artificial gauge field on a four-site plaquette. The dynamical gauge field emerges through the interaction between impurity atoms and particles represented by different spin species. We place one impurity atom on each horizontal link of the plaquette and probe the dynamical field with a third particle that interacts with the impurities and thus generates a back-action.

Q 59.2 Thu 10:45 K 2.020

Cavity-induced artificial gauge field in a Bose-Hubbard ladder — •Catalin-Mihai Halati, Ameneh Sheikhan, and Corinna Kollath — HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

We consider theoretically ultracold interacting bosonic atoms confined to quasi-one-dimensional ladder structures formed by optical lattices and coupled to the field of an optical cavity. The atoms can collect a spatial phase imprint during a cavity-assisted tunneling along a rung via Raman transitions employing a cavity mode and a transverse running wave pump beam. By adiabatic elimination of the cavity field we obtain an effective Hamiltonian for the bosonic atoms, with a self-consistency condition. Using the numerical density matrix renormalization group method, we obtain a rich steady state diagram of self-organized steady states. Transitions between superfluid to Mott-insulating states occur, on top of which we can have Meissner, vortex liquid, and vortex lattice phases. Also a state that explicitly breaks the symmetry between the two legs of the ladder, namely the biased-ladder phase is dynamically stabilized.

Q 59.3 Thu 11:00 K 2.020

A Simple Model for the Temporal Evolution of Cold Dark Matter — •Tim Zimmermann[1], Luca Amendola[1], Massimo Pietroni[2], and Sandro Wimberger[2] — [1]ITP, Universität Heidelberg, 69120 Heidelberg — [2]Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università di Parma, 43124 Parma & INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, 43124 Parma

Cold dark matter (CDM) is typically modeled as a collisionless, irrotational fluid, trapped in its own gravitational potential, obeying the classical Euler-Poisson equations. However, a straight forward analyis shows that CDM can also be treated in a quantum dynamical framework if one chooses a particular ansatz for the wave function. In doing so, the temporal evolution of CDM is governed by a nonlinear Schrödinger equation describing CDM as self-interacting, self-gravitating Bose-Einstein condensate. Modeling the dynamics of cold dark matter in terms of the Gross-Pitaevskii-Poisson system turns out to be an elegant describtion of structure formation comparable to classical cosmological approaches, especially on large cosmic scales. On smaller scales gravitational collapse is balanced by a "quantum pressure" that resembles Heisenbergs' uncertainty principle. We present a comprehensive numerical method to perform the time evolution of the described wave-like CDM. Results for both synthetic and cosmological initial conditions are presented.

Q 59.4 Thu 11:15 K 2.020

Self-consistent spin texture in a quantum gas through opto-magnetical effects — Katrin Kröger, •Manuele Landini, Lorenz Hruby, Nishant Dogra, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

We experimentally realize opto-magnetic coupling between a multilevel atomic BEC and a single mode of a high-finesse optical cavity. We focus on the role of the vectorial component of the polarizability tensor for spinful condensed atoms. We develop a theory in the context of a modified Dicke model and can explain the observed threshold power for the self-organization phase transition as well as the phase of the light in the organized phase depending on the internal state. When preparing a spin mixture, we identify two distinct regimes of coupling. In the regime of density coupling, the self-organization process generates density modulations in the atomic system. By increasing the ratio of the vectorial over the scalar coupling beyond a critical point, we observe the appearance of a new self-organization pattern consisting of magnetization modulations, a spin texture. Our findings demonstrate a direct competition between self-organization patterns in a single mode optical cavity, paving the way to the exploitation of opto-magnetic effects for quantum simulation of long-range magnetic interactions.

Q 59.5 Thu 11:30 K 2.020

supersolidity of lattice Bosons immersed in strongly correlated Rydberg dressed atoms — •Yongqiang Li[1], Andreas Geissler[2], Walter Hofstetter[2], and Weibin Li[3,4] — [1]Department of Physics, National University of Defense Technology, Changsha 410073, P. R. China — [2]Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt/Main, Germany — [3]School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, UK — [4]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, UK

Recent experiments have illustrated that long range two-body interactions can be induced by laser coupling atoms to highly excited Rydberg states. Stimulated by this achievement, we study supersolidity of lattice bosons in an experimentally relevant situation. In our setup, we consider two-component atoms on a square lattice, where one species is weakly dressed to an electronically high-lying (Rydberg) state, generating a tunable, soft-core shape long-range interaction. Interactions between atoms of the second species and between the two species are characterized by local inter- and intra-species interactions. Using a dynamical mean-field calculation, we find two distinctive types of supersolids, where the bare species forms supersolid phases that are immersed in strongly correlated quantum phases, i.e. a crystalline solid or supersolid of the dressed atoms. We show that the interspecies interaction leads to a roton-like instability in the bare species and therefore is crucially important to the supersolid formation.

Q 59.6 Thu 11:45 K 2.020

Coupled order parameters with ultracold atoms in two crossed cavities — •Philip Zupancic[1], Andrea Morales[1], Julian Léonard[1,2], Xiangliang Li[1], Davide Dreon[1], Tilman Esslinger[1], and Tobias Donner[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

The concept of intertwined order describes the simultaneous existence of independent order parameters and can therefore allow materials to feature multiple properties. Examples include multiferroic materials that have coexisting ferroelectric and ferromagnetic orders leading to enhanced functionalities, and materials that are superconducting at high temperatures due to intertwining between charge- and spin-order.

I will report on our recent experimental realization of an intertwined ordered phase in a quantum gas where we can control the interaction between the atoms at the microscopic level. Our system is realized by a BEC that can transit into self-organized phases with the modes of two crossed optical cavities.

For vanishing inter-order coupling we realize a supersolid phase of matter by symmetry enhancement of the composite order parameter to a $U(1)$ symmetry. Here we observe the simultaneous existence of a Higgs and Goldstone mode. Increasing the inter-order coupling, this symmetry breaks down to a $\mathbb{Z}_2 \times \mathbb{Z}_2$, and we observe the emergence of an extended intertwined phase arising from the coupling of the individual order parameters. This coupling enables us to increase or decrease the critical point of one order by controlling the other.

Q 59.7 Thu 12:00 K 2.020

Entanglement entropy across quantum phases of Ultracold Bosons with incommensurate optical lattice due to cavity backaction — •Shraddha Sharma[1], Astrid E. Niederle[2], and Giovanna Morigi[1] — [1]Theoretical Physics, Saarland University, Campus E2.6, D-66123 Saarbrucken, Germany — [2]Fraunhofer Institute for Experimental Software Engineering IESE, Germany

We consider a bosonic gas in a two-dimensional optical lattice. The atoms interact via s-wave scattering and via long range interactions induced by the coupling with a cavity. We determine the phase diagram when the optical lattice wavelength is incommensurate with the cavity mode wavelength using a mean-field ansatz. In this regime we observe, in addition to the Mott-insulator and the superfluid, also a Bose-Glass and a superglass phase, where the density distribution supports the formation of a stable intracavity field. We explore the behaviour and scaling of entanglement entropy and of entanglement spectrum at the phase transitions using a controlled perturbative expansion above the mean-field ground state.

Q 59.8 Thu 12:15 K 2.020

Self organisation of a BEC in two crossed cavities across an atomic resonance — •Davide Dreon, Andrea Morales, Philip Zupancic, Xiangliang Li, Tobias Donner, and Tilman Esslinger — ETH, Zürich, Switzerland

The interaction of a Bose-Einstein condensate (BEC) with the electromagnetic field of an optical cavity is known to exhibit a superradiant phase transition to a self-organized phase. In our experiment, a ^{87}Rb BEC is placed at the mode crossing of two optical cavities. The BEC is illuminated with a 'pump' laser beam whose detuning from the D_2 atomic line determines the interaction regime. We recently explored different red detunings, where the system reduces its potential energy spontaneously forming an attractive lattice in the cavity mode. Here, we have observed a supersolid phase [1,2] and a phase with intertwined order [3]. In contrast, in the blue detuned case the energy of the atoms is increased by the presence of an optical lattice and therefore spontaneous superradiant scattering in the cavity should be inhibited.

I will report on our most recent experimental results on the blue side of the atomic resonance, where we observe, surprisingly, that self-organization is still possible. We measure the phase diagram of the system and explain our findings with simple energy arguments. In addition to the steady state regime typical of red detunings, dynamical instabilities leading to limit cycles of the cavity field amplitude or chaotic behaviors are expected [4].

[1] Nature, 543, 87-90 (2017), [2] arXiv:1704.05803 (to appear in Science), [3] arXiv:1711.07988, [4] PRL 115, 163601 (2015)

Q 59.9 Thu 12:30 K 2.020

Nanofriction & the Aubry-type transition in self-organized systems under the influence of the crystal environment — •Jan Kiethe[1], Ramil Nigmatullin[2], Dimitri Kalincev[1], Thorben Schmirander[1], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland — [2]University of Sydney, Sydney, Autralia

The excellent control over trapped ions enables various applications, such as precision spectroscopy and quantum information. Cooling the ions below the potential energy of the Coulomb system will result in crystals, which can be used as quantum simulators or as emulators for non-equilibrium many-body physics. Furthermore, ion traps offer in-situ access to the crystal dynamics, which is often impossible in the emulated systems. While emulating a boundary of two atomically flat solids with a Coulomb crystal with a local defect, we experimentally and numerically found a transition from sticking-to-sliding. Two signatures of an Aubry-type transition were observed: a soft-mode and a symmetry breaking of the crystal configuration. Here we discuss, based on numerical calculations, how the environment of the ion crystal influences the structure and subsequently the phonon spectrum, in order to determine how robust these signatures are. As the actual interacting surface in this model system is inhomogeneously spaced, we also numerically investigate Coulomb crystals with periodic boundary conditions, which exhibit a constant distance between the sliding ion chains, increasing the interacting surface to the complete crystal.

Q 60: Annual General Meeting of the Quantum Optics and Photonics Division

Time: Thursday 12:45–13:30 Location: K 2.013

Division Q Matters

Q 61: Precision Spectroscopy VI - neutrals and ions (joint session A/Q)

Time: Thursday 14:00–16:00 Location: K 1.016

Invited Talk Q 61.1 Thu 14:00 K 1.016

News from the "Proton Radius Puzzle" — •Randolf Pohl — Johannes Gutenberg Universität Mainz

The *Proton Radius Puzzle* [1] is the 5 sigma discrepancy between the charge radius measured in muonic hydrogen [2] on the one hand, and in regular hydrogen and elastic electron scattering on the other [3]. I will report on several new measurements in muonic and electronic atoms, which have recently started to shed light on the discrepancy. These include measurements in muonic deuterium [4], helium-3 and helium-4, as well as a new measurement in regular hydrogen [5]. In the outlook, I will present ongoing and planned measurements of the CREMA Collaboration targeting the (magnetic) Zemach radius of the proton [6], and the charge radii of other light nuclei.

[1] J.C. Bernauer, R. Pohl, Spektrum der Wiss., April 2014
[2] A. Antognini et al., (CREMA Collab.), Science 339, 417 (2013)
[3] P. Mohr et al. (CODATA-2014), Rev. Mod. Phys. 88, 035009 (2016)
[4] R. Pohl et al., (CREMA Collab.), Science 353, 669 (2016)
[5] A. Beyer et al., Science 358, 79 (2017)
[6] R. Pohl et al., J. Phys. Soc. Japan Conf. Proc. 18, 011021 (2017)

Q 61.2 Thu 14:30 K 1.016

A Network Approach to Atomic Spectra — •David Wellnitz[1], Julian Heiss[1], Armin Kekić[1,2], Sebastian Lackner[3], Andreas Spitz[3], Michael Gertz[3], and Matthias Weidemüller[1,4] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]École Normale Supérieure, Paris, Frankreich — [3]Institut für Informatik, Im Neuenheimer Feld 205, 69120 Heidelberg, Germany — [4]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

We demonstrate a network-inspired approach for treating atomic spectroscopy data. Nodes of the network represent states, while links represent transitions between them. We find that such spectroscopic networks exhibit an anti-community structure, microscopically characterized by equal quantum numbers of the electronic angular momentum. Using state-of-the-art methods for link prediction, transitions missing in the data can be identified without having to rely upon a microscopic model of the atom. We apply our methods to spectroscopic networks of hydrogen, helium and iron. Implications of our network approach for understanding complex atomic structure are discussed.

Q 61.3 Thu 14:45 K 1.016

Analytical methods for the extraction of an ionization potential from dense atomic spectra — •Pascal Naubereit, Reinhard Heinke, Dominik Studer, Marcel Trümper, and Klaus Wendt — Institut für Physik, Johannes Gutenberg-Universität Mainz, D-55128 Mainz, Germany

Complex atomic structures can exhibit intrinsic quantum chaotical behavior. Correspondingly, this prevents a clear identification and assignment of energy levels. However, for the determination of the ionization potential applying e.g. resonance ionization spectroscopy, the convergence of Rydberg series is the most precise direct measurement method. If the possibility to directly allocate and identify a series of Rydberg levels amongst hundreds of other resonances is not available, one may rely on more comprehensive analytical investigation methods for these atomic spectra. In this presentation, several approaches to extract a value for an unknown ionization potential from highly dense atomic spectra are compared. In addition, the applicability of the methods to atomic systems of increasing complexity, namely sodium, holmium, promethium and protactinium, is examined.

Q 61.4 Thu 15:00 K 1.016

Laser spectroscopy on the radioactive element promethium — •Dominik Studer[1], Holger Dorrer[2], Carlos Guerrero[3], Stephan Heinitz[4], Reinhard Heinke[1], Pascal Naubereit[1], Sebastian Raeder[5], Dorothea Schumann[4], and Klaus Wendt[1] — [1]Institut für Physik, JGU Mainz, Germany — [2]Institut für Kernchemie, JGU Mainz, Germany — [3]Universidad de Sevilla, Spain — [4]PSI, Villigen, Switzerland — [5]Helmholtz Institut Mainz, Germany

Promethium ($Z = 61$) is an exclusively radioactive element with short half-lives of up to 17 years. Consequently, Pm sample amounts that can be safely handled in laboratories are small and data on atomic transitions is scarce. Apart from the heavy actinides and transactinides, Pm is the last element where the first ionization potential (IP) has not been directly measured until now.

Here we present the results from resonance ionization spectroscopy of ^{147}Pm ($t_{1/2} = 2.6$ y) in a hot cavity laser ion source. More than 1000 new optical transitions were recorded in the spectral ranges from 415 - 470 nm and 800 - 910 nm using pulsed Ti:sapphire lasers. Although a straightforward analysis of Rydberg convergences was prevented by complex spectra for high excitation energies, the IP could be determined with a precision of better than 1 cm^{-1} by measuring the electric field ionization threshold for several weakly bound states. Finally the hyperfine structure of two subsequent transitions in a newly developed RIS scheme was measured with experimental linewidths of ≈ 120 MHz as preparation for the extraction of nuclear structure parameters in on-line spectroscopy experiments on short-lived Pm isotopes.

Q 61.5 Thu 15:15 K 1.016

Spectroscopy of the $6S_{1/2} \rightarrow 5D_{5/2}$ electric quadrupole transition of atomic cesium — •Sebastian Pucher, Alexandre Dareau, Philipp Schneeweiss, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

The $6S_{1/2} \rightarrow 5D_{5/2}$ electric quadrupole transition of cesium is studied experimentally via Doppler-free spectroscopy in hot vapor. The hyperfine structure of this transition is resolved, and the line intensities and optical pumping dynamics are analyzed. In an additional experiment, the lifetime of the $5D_{5/2}$ state is determined by recording the fluorescence light associated to the decay of atoms from the intermediate $6P_{3/2}$ state to the electronic ground state, in excellent agreement with literature values. Based on these results, we plan future experiments with laser-cooled atoms close to surfaces, e.g., in order to enhance the quadrupole coupling.

Q 61.6 Thu 15:30 K 1.016

Absolute Quantum Gravimeter: an autonomous and mobile atom interferometer operating at the 1E-10 level of stability over months to support Geosciences — •Jean Lautier Gaud, Vincent Ménoret, Pierre Vermeulen, and Bruno Desruelle — Muquans, Talence, France

This paper reports recent remarkable achievements of cold-atom technologies and related operational devices in the area of Quantum Sensing and Metrology which occurred at Muquans in 2017. We will present in detail the status of the Absolute Quantum Gravimeter (AQG) that has left the laboratory for geophysical studies. The AQG is an industry-grade commercial gravity sensor which today meets the objective to provide a gravimeter based on atom interferometry with laser-cooled atoms as a mobile turn-key device. We report on an operational stability of the absolute measurements of g at the 1E-10 level in various types of environment during month-long continuous acquisition periods. The first unit of the AQG has traveled more than 7000 km, so we will comment on the last measurement campaigns and comparisons performed by the AQG. These have in particular validated the repeatability of the measurements at the 1E-9 level, the ease of use and the robustness of such technology. This paper will also be the occasion to describe in more details the high degree of maturity of several key enabling technologies such as intelligent integrated laser systems that can help Quantum Technologies with cold atoms taking-off for a wider range of applications in Quantum Computing, Quantum Simulation and Quantum Communication.

Q 61.7 Thu 15:45 K 1.016

Ba^+ Isotope shift studies in preparation of atomic parity violation measurement — •Nivedya Valappol[1], Elwin Dijck[1], Aswin Hofsteenge[1], Olivier Grasdijk[1], Amita Mohanty[2], Mayerlin Portela[3], Lorenz Willmann[1], and Klaus Jungmann[1] — [1]Van Swinderen Institute, FSE, University of Groningen, The Netherlands — [2]NISER, Bhubaneswar, India — [3]Laboratorio de Òptica Cuàntica, Universidad de los Andes, Bogotà D.C., Colombia

The Ba^+ ion, has a structure of spectral lines similar to heavy single valence electron alkali atoms. It is precisely studied by laser spectroscopy in presence of several light fields in order to prepare for a measurement of atomic parity violation (APV). Measurements in heavy alkali earth ions (e.g. Ba^+ and Ra^+) permit the precise determination of the weak mixing (Weinberg) angle $\sin^2\theta_W$ with improvement over the previous best measurement in neutral Cs by a factor of 5 in a week of actual measurement time. The transition frequencies for the $6s^2S_{1/2}$ - $6p^2P_{1/2}$, $6p^2P_{1/2}$ - $5d^2D_{3/2}$ and $6s^2S_{1/2}$ - $5d^2D_{3/2}$ transitions in $^{138}Ba^+$ have been measured to 10^{-10} relative accuracy employing a line shape model for single ions in a radio frequency Paul trap [1]. These measurements have been extended to $^{134,136}Ba^+$. Together with a determination of the lifetime of the excited $5d^2D_{5/2}$ state these measurements provide for a stringent test of calculations, the accuracy of which is pivotal for a determination of $\sin^2\theta_W$. The observed lifetime is 25.8(5)s. Being about 5s shorter than previous measurements and calculations agreeing with them, it provides for a puzzle.

[1] E. A. Dijck et al., Phy. Rev. A 91, 060501(R)(2015)

Q 62: Poster: Quantum Optics and Photonics V

Time: Thursday 16:15–18:15 Location: Redoutensaal

Q 62.1 Thu 16:15 Redoutensaal

Creating Homogeneous Two-Dimensional Fermi Gases — •Fynn Förger, Lennart Sobirey, Niclas Luick, Klaus Hueck, Jonas Siegl, Thomas Lompe, and Henning Moritz — Institut fuer Laserphysik, Universitaet Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

In this poster we present the creation and investigation of homogeneous two-dimensional Fermi gases. These gases are well suited to study the intriguing interplay of reduced dimensionality and strong interactions.

To create a two-dimensional system we load our atoms into a strong confining 1D optical lattice. This freezes out any motional degrees of freedom in the third direction. To load 2D Fermi gases both in single and double layer configuration, we developed a method to detect the occupation of the different layers in a single shot measurement.

Homogeneity is achieved by confining the atoms in a box potential in the remaining two directions, which is formed by a repulsive ring-shaped potential created with an optical setup employing three axicons.

We demonstrate how the in plane momentum distributions can be obtained using matter wave focusing and how spin removal can mitigate interaction effects during time of flight. Finally, we report on a novel method to calibrate high intensity absorption imaging to high precision using relative measurements of the momentum transferred to the atoms by the imaging light.

Q 62.2 Thu 16:15 Redoutensaal

Exploring the doped Fermi-Hubbard model in low dimensions — •Jayadev Vijayan[1], Timon Hilker[1], Guillaume Salomon[1], Joannis Koepsell[1], Michael Höse[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institute für Quantenoptik, Garching — [2]Fakultät für Physik, Ludwig- Maximilians-Universität, München

We use ultracold fermionic lithium atoms in an optical lattice to realize synthetic one dimensional Fermi-Hubbard chains. Using a quantum gas microscope that can resolve local spin and density, we study emerging antiferromagnetic correlations as a function of doping and magnetization. We see signatures of spin-charge separation in the one dimensional chains by using three point correlation functions, opening the route towards a direct measurement of the complex correlations arising in two dimensions. We further observe the change of the wave vector of the spin correlations as a function of density and magnetization, which can be well described by Luttinger-liquid theory. Finally we report on ongoing studies of the system in the crossover from one to two dimensions.

Q 62.3 Thu 16:15 Redoutensaal

Detecting correlations in deterministically prepared quantum states with single-atom imaging — •Andrea Bergschneider, Vincent M. Klinkhamer, Jan Hendrik W. Becher, Ralf Klemt, Gerhard Zürn, Philipp M. Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg

We deterministically prepare correlated quantum states consisting of few fermions in a double-well potential. A newly developed imaging scheme for fermionic Lithium allows us to detect these correlations on a single-atom level and with spin resolution.

The detection method uses fluorescence imaging at high magnetic fields where the optical transitions for the used hyperfine states are almost closed. With a high-resolution objective we detect about 20 scattered photons per atom on an EMCCD camera. This is sufficient to identify and locate single atoms. We can apply this scheme insitu or after an expansion in time-of-flight and additionally resolve the spin by subsequently adressing the different hyperfine states.

Using this, we measure the two-particle momentum correlations and thereby probe the spatial symmetry of the two-particle wavefunction. Combining momentum and insitu information, we determine a witness for mode and particle entanglement present in the system. The high contrast and the scalability of our detection technique will allow us to go beyond measuring two-particle correlations and characterize many-body quantum states.

Q 62.4 Thu 16:15 Redoutensaal

Correlations of strongly attractive few-fermion systems — •Philipp M. Preiss, Vincent Klinkhamer, Ralf Klemt, Andrea Bergschneider, Jan Hendrik Becher, Gerhard Zürn, and Selim Jochim — Physikalisches Institut, Universität Heidelberg

Strongly coupled quantum systems are characterized by the correlations between their constituents. We prepare systems with strong attractive interactions containing few 6Li atoms in an optical microtrap. We release the atoms from the trap and measure the positions of the atoms with a spin-resolved single-atom sensitive imaging method after time-of-flight. From these positions, we construct the two-body correlation functions.

Our measurements are ideally suited to study the effects of interactions and quantum statistics in few-particle systems. The measured correlation functions can give access to the microscopic properties of fermionic quantum states and can be used to explore the few-body limit of hydrodynamics or to detect pairing phenomena in the BEC-BCS crossover.

Q 62.5 Thu 16:15 Redoutensaal

Towards a lithium quantum gas microscope for small quantum systems — •Andreas Kerkmann, Michael Hagemann, Mathis Fischer, Benno Rem, Christof Weitenberg, and Klaus Sengstock — Institut für Laserphysik, Hamburg, Germany

We are setting up a new quantum gas microscope for the detection of degenerate samples of ^6Li/ ^7Li atoms to study strong correlations in small quantum systems. Our design consists of a compact 2D-/ 3D-MOT loading scheme and an all-optical approach for the preparation of degenerate samples. In our poster, we provide information about the details of the design and the current status of the experiment.

Q 62.6 Thu 16:15 Redoutensaal

An experiment for the study of small Hubbard models with rapid repetition rate — •Martin Schlederer, Phillip Wieburg, Alexandra Mozdzen, Thomas Lompe, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, Hamburg, Deutschland

Investigating the Fermi-Hubbard model with cold atoms is typically done by evaporatively cooling an ultracold Fermi gas and loading it into a large optical lattice. In contrast, we plan to assemble small Fermi-Hubbard type systems site by site using optical microtraps. Each microtrap will contain a single atom cooled to the vibrational ground state by Raman-sideband cooling [1]. This technique combines fast experimental cycle times with single site addressability and detection and will allow to study the fundamental processes governing the Fermi-Hubbard model in a bottom-up approach.

The poster will present the current status of the experiment: We trap 40K atoms in a magneto-optical trap and cool them to sub-Doppler temperatures using a gray molasses . After magnetic transport to the science region they are loaded in optical lattices where in the next step Raman sideband cooling will be investigated. In order to load the atoms into flexible configurations of microtraps and to manipulate them individually, we will use two high resolution microscopes objectives located inside the vacuum chamber.

[1] A.M. Kaufman et al., Physical Review X 2, 041014 (2012).

Q 62.7 Thu 16:15 Redoutensaal

Coherent Manipulation of Spin Correlations in the Hubbard Model — •Nicola Wurz[1], Chun Fai Chan[1], Marcell Gall[1], Jan Henning Drewes[1], Eugenio Cocchi[1,2], Luke Alexander Miller[1,2], Daniel Pertot[1], Ferdinand Brennecke[1], and Michael Köhl[1] — [1]Physikalisches Institut, University of Bonn, Germany — [2]Cavendish Laboratory, University of Cambridge, United Kingdom

We coherently manipulate spin correlations in a two-component atomic Fermi gas loaded into an optical lattice using spatially and time-resolved Ramsey spectroscopy combined with high-resolution *in situ* imaging. This novel technique allows us not only to imprint spin patterns but also to probe the static magnetic structure factor at arbitrary wave vector, in particular the staggered structure factor. From a measurement along the diagonal of the 1st Brillouin zone of the optical lattice, we determine the magnetic correlation length and the individual spatial spin correlators. At half filling, the staggered magnetic structure factor serves as a sensitive thermometer for the spin temperature, which we employ to study the thermalization of spin and density degrees of freedom during a slow quench of the lattice depth.

Q 62.8 Thu 16:15 Redoutensaal

The Bose Polaron in an ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li — •Melina Filzinger[1], Binh Tran[1], Manuel Gerken[1], Markus Neiczer[1], Stephan Häfner[1], Bing Zhu[1], Matthias Weidemüller[1,2], Moritz Drescher[3], and Tilman Enss[3] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China — [3]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 19, 69120 Heidelberg

An ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li is well suited for the investigation of the Bose polaron. In this scenario a single Li impurity is immersed in a Cs BEC and interacts with its phonon excitations, mimicking the Fröhlich polaron problem from solid-state physics. Tuning the sign and strength of the interaction between Li and Cs via Feshbach resonances enables us to study both the repulsive and attractive polaron. We are particularly interested in the study of the quench dynamics of the Bose polaron and the emergence of Efimov physics in its attractive branch.

We give an overview of our experimental approach towards creating and studying the Bose polaron in our system. With an improved imaging system and radiofrequency-setup we are able to manipulate and detect small numbers of Li impurities in a controlled way. Combining our experimental efforts with theoretical investigations of the BEC density profile after a quench, we are aiming to distinguish the Landau-Pekar and bubble polaron.

Q 62.9 Thu 16:15 Redoutensaal

Towards double degeneracy of a Bose-Fermi mixture of ^{133}Cs and ^{6}Li — •Markus Neiczer[1], Manuel Gerken[1], Binh Tran[1], Melina Filzinger[1], Stephan Häfner[1], Bing Zhu[1], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

An ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li is an interesting system for the study of ground state polar molecules due to the large electric dipole moment as well as for the investigation of polarons because of the large mass imbalance and the tuneability of intra- and interspecies interactions. For these studies reaching a doubly degenerate quantum gas is a favourable experimental condition. We design a new cooling and trapping scheme for ^{6}Li which combines a time averaged crossed dipole trap and gray molasses cooling, improving the starting conditions for further evaporative cooling. The enhanced phase space density of ^{6}Li atoms allows for sympathetic cooling of ^{133}Cs, aiming for double degeneracy.

Q 62.10 Thu 16:15 Redoutensaal

Higher partial wave Feshbach resonances in an ultracold mixture of ^{6}Li and ^{133}Cs atoms — •Manuel Gerken[1], Stephan Häfner[1], Bing Zhu[1], Binh Tran[1], Juris Ulmanis[1], Eberhard Tiemann[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

We present measurements and analysis of higher partial wave Feshbach resonances in an ultracold mixture of fermionic ^{6}Li and bosonic ^{133}Cs atoms. We observe five p-wave ($l = 1$) and three d-wave ($l = 2$) resonances in the two energetically lowest entrance channels by magnetic field dependent atom-loss spectroscopy. We observe doublet and triplet structures in the p-wave resonances corresponding to different m_l, the projections of the pair rotation angular momentum. We attribute the lifted degeneracy in the m_l states to spin-spin and spin-rotation coupling in the molecules. The observed d-wave Feshbach resonances allow us to refine the LiCs singlet and triplet molecular potential curves at large internuclear separations.

Q 62.11 Thu 16:15 Redoutensaal

Interacting Rydberg Polaritons for Photonic Quantum Logic — •Thomas Stolz, Steffen Schmidt-Eberle, Daniel Tiarks, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

The strong dipole-dipole interaction between Rydberg atoms has enabled remarkable experimental success ranging from quantum information processing with single atoms to observation of exotic many-body states. The interaction between Rydberg excitations can also be used to create a large effective interaction between photons. To this end, one addresses Rydberg states with electromagnetically induced transparency. This creates a quasiparticle, called Rydberg polariton, which consists of a photonic component and a co-propagating atomic Rydberg excitation. The large interaction between the Rydberg components manifests itself in the form of a giant optical nonlinearity [1]. A central goal in the field of Rydberg polaritons is the realization of photonic quantum logic. This line of research has seen impressive progress in the last few years, including the demonstration of single-photon transistors [2,3,4] and the observation of large conditional phase shifts at the single photon level [5,6]. We report on our recent progress on using Rydberg polaritons for photonic quantum logic.

[1] J. D. Pritchard et al. PRL **105**, 193603 (2010). [2] S. Baur et al. PRL **112**, 073901 (2014). [3] H. Gorniaczyk et al. PRL **113**, 053601 (2014). [4] D. Tiarks et al. PRL **113**, 053602 (2014). [5] D. Tiarks et al. Sci. Adv. **2**, e1600036 (2016). [6] J. D. Thompson et al. Nature **542**, 206 (2017).

Q 62.12 Thu 16:15 Redoutensaal

Towards an efficient on-demand single-photon source based on atomic microcells — •Florian Christaller, Fabian Ripka, Hao Zhang, Annika Belz, Harald Kübler, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

Photonic quantum devices based on atomic vapors at room temperature combine the advantages of atomic vapors being intrinsically reproducable as well as semiconductor-based concepts being scalable and integrable. One key device in the field of quantum information are on-demand single-photon sources. A promising candidate for realization relies on the Rydberg blockade effect.

Coherent dynamics to Rydberg states [1] and sufficient Rydberg interaction strengths [2] have already been demonstrated in thermal vapors. Also in a pulsed FWM scheme these phenomena could be observed [3,4]. Additionally, time-resolved probing of collective Rydberg excitation has been performed [5], revealing a lifetime long enough for effective Rydberg-Rydberg interactions.

Here we report on different multi-level schemes which exploit the latest developments in laser technology. We aim at high repetition rate and high fidelity of single-photon generation.

[1] Huber et al., PRL 107, 243001 (2011)
[2] Baluktsian et al., PRL 110, 123001 (2013)
[3] Huber et al., PRA 90, 053806 (2014)
[4] Chen et al., Appl. Phys. B, 122:18 (2016)
[5] Ripka et al., Phys. Rev. A, 053429 (2016)

Q 62.13 Thu 16:15 Redoutensaal

Surface Plasmon Enhanced Multipole Transitions of Rydberg Atoms — •Yijia Zhou and Weibin Li — School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD, UK

The dipole approximation is widely used in describing light-matter interactions due to the fact that sizes of emitters are far smaller than wave lengths of the coupling light. This is changed qualitatively when an emitter approaches to two dimensional surfaces, where dispersion relations of surface plasmons turn out to be nonlinear and their wave length can be shrunken up to hundreds of times relative to light in free space. This can enhance the otherwise forbidden higher order multipolar transitions and multiphoton emissions (Rivera2016). Emitters have to be located a few nm above the surface, and that the shrinking factor is typically larger 100, which are experimentally challenging. We study nondipole effects using Rydberg atoms instead of groundstate atoms. Large orbital sizes of the electron in electronically high-lying states bring an additional amplifying factor to the light-atom coupling, which depends nonlinearly on the principal quantum numbers n. When $n \gg 1$, this significantly enhances multipolar couplings, permitting us to observe these effects with smaller shrinking factors, as well as at large separations between Rydberg atoms and the surface.

Q 62.14 Thu 16:15 Redoutensaal

Rydberg excitations of cold atoms inside a hollow-core fiber — •Parvez Islam, Maria Langbecker, Mohammad Noaman, Chantal Voss, Ronja Wirtz, Wei Li, and Patrick Windpassinger — Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Cold atoms inside hollow-core fibers present a promising candidate to study strongly coupled light-matter systems. Combined with the long range Rydberg interaction which is controlled through an EIT process, a corresponding experimental setup should allow for the generation of a strong and tunable polariton interaction.

We present our measurements of cold Rydberg excitations inside a hollow-core fiber to characterize the Rydberg atom-fiber interaction by using electromagnetically induced transparency (EIT) signals [1]. A time resolved detection method was implemented to distinguish between EIT excitation and atom loss. In a separate setup at room temperature, we also investigate the influence of different types of fiber coatings and geometries on Rydberg EIT. Here we observe signals for levels up to the 85D state.

[1] M. Langbecker, M. Noaman, N. Kjaergaard, F. Benabid, and P. Windpassinger, Phys. Rev A 96, 041402(R) (2017).

Q 62.15 Thu 16:15 Redoutensaal

3D image reconstruction using symmetries applied to cold Rydberg gases — •Henrik Zahn[1], Renato Ferracini Alves[1], Miguel Ferreira Cao[1], Titus Franz[1], Adrien Signoles[2], Nithiwadee Thaicharoen[1], Gerhard Zürn[1], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Laboratoire Charles Fabry, Institut d'Optique, 2 Avenue Augustin Fresnel 91127 Palaiseau -France — [3]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

This poster introduces an algorithm to reconstruct a three dimensional object from its two dimensional projection. It discretizes the problem in a coordinate system given by *a priori* knowledge of the object's symmetry. The resulting system of linear equations can be solved in a least squares sense. The method is applied to a strongly interacting Rydberg gas in order to study saturation effects and scaling laws in the excitation dynamics.

Q 62.16 Thu 16:15 Redoutensaal

Measuring non-linear susceptibility in a Rydberg EIT medium — •Clément Hainaut[1], Annika Tebben[1], Valentin Walther[2], Renato Ferracini Alves[1], Yongchang Zhang[2], Andre Salzinger[1], Nithiwadee Thaicharoen[1], Gerhard Zürn[1], Thomas Pohl[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 226, 69129 Heidelberg, Germany — [2]Department of Physics and Astronomy, Ny Munkegade 120, building 1525 420, 8000 Aarhus C, Denmark — [3]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

Rydberg-Rydberg interactions affect the propagation of light in a cold atomic gas under EIT conditions. Due to this interaction, the system reveals an effective photon-photon interaction which results in a non-local, non-linear susceptibility of the medium.

In our work, we want to experimentally measure the enhancement of the susceptibility due to resonant Rydberg dressing of the atoms. To do so, we work in the limit of low optical density of the probe beam per blockade radius. In this regime, the probe light field experiences substantial non-linear effects which affect its intensity distribution after propagation. We implement a spatially structured probe beam and a diffraction limited imaging system for measuring correlations in the intensity pattern after propagation through the medium.

Q 62.17 Thu 16:15 Redoutensaal

Relaxation of an isolated Rydberg-spin system in an external field — •Nithiwadee Thaicharoen[1], Adrien Signoles[1], Miguel Ferreira-Cao[1], Renato Ferracini Alves[1], Titus Franz[1], Andre Salzinger[1], Asier Piñeiro Orioli[2], Martin Gärttner[3], Jürgen Berges[2,4], Shannon Whitlock[1,5], Gerhard Zürn[1], and Matthias Weidemüller[1,6] — [1]Physikalisches Institut, Universität Heidelberg, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Germany — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Germany — [4]ExtreMe Matter Institute EMMI, Darmstadt, Germany — [5]IPCMS and ISIS, University of Strasbourg and CNRS, Strasbourg, France — [6]Shanghai Branch, University of Science and Technology of China, Shanghai, China

Dipolar interacting Rydberg spin systems have been ideal platforms to study non-equilibrium phenomena of isolated quantum systems. Their long-range interactions provide opportunities to investigate dynamics of correlated many-body quantum systems with beyond nearest-neighbor coupling. In this work, we present an experimental realization of a dipolar spin-1/2 model by coupling two strongly interacting Rydberg states utilizing a microwave field. With an ability to fully control phase, amplitude, and frequency of the microwave field, we perform arbitrary initial state preparation and study time evolution of the spin system under designated interactions. The resulting global magnetizations together with theoretical models suggest that the relaxation of the spin system is due to primordial quantum fluctuations while single particle decoherence does not play an important role.

Q 62.18 Thu 16:15 Redoutensaal

Kinetic Field Theory - From cosmology to cold atoms — •Andre Salzinger[1], Elena Kozlikin[2], Martin Pauly[2], Alexander Schuckert[3], Robert Lilow[2], Matthias Bartelmann[2], and Matthias Weidemüller[1,4] — [1]Physikalisches Institut, Heidelberg — [2]Institut für Theoretische Astrophysik, Heidelberg — [3]Institut für Theoretische Physik, Heidelberg — [4]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

Cosmic structure formation can be described by a classical path integral formalism. We apply such a theoretical framework to the evolution of two-point density correlators in an ensemble of Rydberg atoms. Initial correlations due to excitation blockade or facilitation are shown to decrease significantly faster under the influence of strong Rydberg-Rydberg interaction, compared to a free evolution. We discuss the experimental conditions under which this effect becomes strong enough to influence many-body experiments on microsecond time-scales. We further compare our computational procedure to standard methods from molecular dynamics.

Q 62.19 Thu 16:15 Redoutensaal

Proposal to identify Thermal and Non-Thermal fixed points in a strongly interacting Rydberg gas. — •Titus Franz[1], Renato Ferracini Alves[1], Miguel Ferreira Cao[1], Adrien Signoles[1], Nithiwadee Thaicharoen[1], Shannon Whitlock[1], Gerhard Zuern[1], Jürgen Berges[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

Ultracold atoms excited to high lying Rydberg states offer an ideal platform for studying the non-equilibrium properties of long-range interacting quantum spin systems under a controlled environment. Due to the many competing effects like disorder, external fields and fluctuations, it is still an open question whether the system with the underlying Heisenberg XXZ-Hamiltonian equilibrates and reaches a thermal or non-thermal fixed point. This poster proposes a detection scheme for the absence of diffusion in a possible Many-Body-Localization phase by a measurement of the breakdown of Linear Response Theorem and the persistence of initial order after relaxation dynamics.

Q 62.20 Thu 16:15 Redoutensaal

Measuring Spin Magnetization in a Two-Level Rydberg System Using State Selective Field Ionization — •Alexander Müller[1], Renato Ferracini Alves[1], Titus Franz[1], Clément Hainaut[1], Nithiwadee Thaicharoen[1], Gerhard Zürn[1], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Ruprecht-Karls-Universität, Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

We use a strongly interacting Rydberg sample to implement a spin 1/2 system composed of two different Rydberg levels. In order to accurately measure the global spin magnetization, we will implement a state selective field ionization scheme. This will be done by ramping an electrical field to temporally separate the ionization for different Rydberg levels. We will present first measurements of the ion signal from a micro-channel plate detector, calculations for the ionization probability of Rydberg atoms in a ramped electrical field and calculations of the ion trajectories. In the future, this technique will be used to study relaxation spin-dynamics and to test Thermalization in linear response theory.

Q 62.21 Thu 16:15 Redoutensaal

High resolution microscopy of cold atoms — Lea Steinert, •Raphael Nold, Markus Stecker, József Fortágh, and Andreas Günther — Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

We have developed a novel quantum gas microscope based on ionization of atoms and a high resolution ion optics. The system achieves a magnification up to 1000 and a theoretical resolution limit below 100nm. The microscope consists of four electrostatic lenses and a microchannel plate in conjunction with a delay line detector. This allows for observation of ultracold ground state as well as Rydberg atoms with single atom sensitivity and high temporal and spatial resolution.

In our experiments, we use the high temporal resolution of the ion-microscope to measure the resonant dipole-dipole interaction of Förster resonances via state selective field ionization. Additionally, we show a direct measurement of the excitation blockade for strongly Stark-shifted Rydberg states close to the classical ionization limit. In this regime, the blockade radius can be sensitively adjusted by small changes of the electric field, opening up new perspectives for quantum simulators.

Q 62.22 Thu 16:15 Redoutensaal

Tailoring ionization of highly Stark shifted Rubidium Rydberg states — •Jens Grimmel, Markus Stecker, Manuel Kaiser, Peter Zwissler, Florian Karlewski, Andreas Günther, and József Fortágh — Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen,

Rydberg atoms are extremely sensitive to electric fields and consequently have a rich Stark spectrum. At sufficiently high electric fields these states start to ionize due to tunneling through the potential barrier as well as direct coupling to the continuum. This region is of particular interest for tailoring the ionization process to certain needs, for example in order to create cold ions and electrons for microscopy applications.

In our numerical calculations we calculate the eigenvalues and eigenvectors of a matrix representation of a Hamiltonian including a complex absorbing potential (CAP) to accurately predict the ionization spectra of Rydberg states beyond the classical ionization threshold. The CAP is adjusted to the external electric field, which allows us to calculate a whole range of the spectrum with only one free parameter. We find good agreement between the results from these calculations and the experimental data of Stark maps for Rubidium Rydberg atoms with principal quantum numbers up to 70 and are able to identify Stark shifted states with ionization rates that can be controlled by fine tuning the external electric field.

Q 62.23 Thu 16:15 Redoutensaal

Design and characterization of a low-cost cateye laser for scientific applications — •Shubha Deutschle, Simon Schuster, Philip Wolf, Max Eisele, Sonja Lorenz, Claus Zimmermann, József Fortágh, and Andreas Günther — Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen

For various applications in quantum optics, tunable lasers with single mode operation, narrow linewidth and high mechanical stability are required. We show the setup and design of an affordable external cavity diode laser, which meets these requirements using a retroreflective system, an interference filter and wedge prisms for easy adjustment of the beam path. The laser is equipped with a self-build electronic board, holding a diode protection circuit and a frequency modulation unit. With a bandwidth of 40MHz, it can be used for multiple laser locking schemes. We measure the linewidth of the laser, using a self-heterodyne interferometer, to be 50 kHz.

Q 62.24 Thu 16:15 Redoutensaal

Optical transport of ultracold atoms for the production of groundstate RbYb — •Tobias Franzen, Bastian Pollklesener, Alexander Mietke, and Axel Görlitz — Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf

Ultracold dipolar molecules constitute a promising system for the investigation of topics like ultracold chemistry, novel interactions in quantum gases, precision measurements and quantum information.

Here we report on a versatile transport apparatus for the production of ultracold RbYb molecules. This setup constitutes an improvement of our old apparatus, where the interactions in RbYb and possible routes to molecule production have already been studied extensively [1,2]. In the new setup a major goal is the efficient production of ground state RbYb molecules.

We employ optical tweezers to transport individually cooled samples of ultracold Rb and Yb from their separate production chambers to a dedicated science chamber. Here we transfer the atoms to a crossed dipole trap, where further evaporative cooling creates a starting point for the exploration of interspecies interactions and pathways towards ground state molecules.

[1] M. Borkowski et al., PRA 88, 052708 (2013)
[2] C. Bruni et al., PRA 94, 022503 (2016)

Q 62.25 Thu 16:15 Redoutensaal

Cavity-controlled chemical reactions of ultracold atoms — Tobias Kampschulte[1], •Simon Rupp[1], Jan Schnabel[2], Andreas Köhn[2], and Johannes Hecker Denschlag[1] — [1]Inst. f. Quantenmaterie, Universität Ulm — [2]Inst. f. Theoretische Chemie, Universität Stuttgart

Ultracold molecules can be formed from ultracold atoms by photoassociation involving a spontaneous emission process, resulting in a number of final states. Here we want to use strong coupling to an optical cavity to selectively enhance the creation of a certain final state. During this process, a photon will be emitted into the cavity mode which can be detected. A collective enhancement of the effect would enable “superradiant chemistry”.

In addition, we want to use the cavity for direct, state-selective and non-destructive optical detection of ultracold molecules. Moreover, collective probing of an ensemble of molecules could induce nonclassical correlations, such as squeezed states of a molecular degree of freedom.

For the experiment, we are integrating a high-finesse optical microcavity into an existing Rb_2 BEC apparatus where Rb_2 molecules can be produced by magneto- and photoassociation.

The theoretical challenge lies in the precise calculation of molecular potential surfaces and optical transition moments, in particular for trimers and more complex molecules.

Q 62.26 Thu 16:15 Redoutensaal

Formation of ultracold ^{6}Li^{133}Cs Feshbach molecules — •Jonas Matthies[1], Manuel Gerken[1], Binh Tran[1], Stephan Häfner[1], Melina Filzinger[1], Markus Neiczer[1], Bing Zhu[1], and Matthias

Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

An ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li is well suited for the study of a dipolar gas of ultracold ground state molecules with large dipole moments. The formation of Feshbach molecules is a prerequisite for the creation of ground state molecules by coherent transfer through a stimulated Raman adiabatic passage (STIRAP). We report on the formation of ^{6}Li^{133}Cs Feshbach molecules via the magneto-association technique. The Feshbach molecules are investigated at three s-wave resonances with widths of 0.37G, 4.22G and 57.45G. We compare the formation efficiency and lifetime of the molecules for the three different resonances and identify the best conditions for STIRAP transfer.

Q 62.27 Thu 16:15 Redoutensaal

Feshbach resonances and degenerate quantum mixtures of bosonic sodium and potassium — •Philipp Gersema, Torben Schulze, Torsten Hartmann, Kai Voges, Jannis Schnars, Matthias Gempel, Eberhard Tiemann, Alessandro Zenesini, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover

Ultracold polar ground state molecules provide an excellent basis for the studies of quantum chemistry and exotic dipolar quantum phenomena. A good and well known starting point for the production of these molecules are ultracold atomic quantum gas mixtures.

Among the alkali atoms, sodium and potassium serve as ideal candidates for the production and investigation of cold molecules. Cooling strategies for both species are well explored, and NaK molecules in their rovibrational ground state feature a large dipole moment as well as chemical stability against exchange reactions.

We present our current effort towards the production of ultracold bosonic ^{23}Na^{39}K molecules. To this end, we study the scattering properties in different spin states by experimentally observing several magnetic Feshbach resonances and loss minima. These provide us highly tunable tools which we employ to succesfully create quantum degenerate Bose-Bose mixtures. In addition, we describe our progress for the production of Feshbach molecules and the envisioned coherent two-photon pathway into ground state molecules.

Q 62.28 Thu 16:15 Redoutensaal

A magic 1D lattice for ultracold, polar NaK molecules — •Frauke Seeßelberg[1], Xin-Yu Luo[1], Ming Li[2], Scott Eustice[1], Svetlana Kotochigova[2], Immanuel Bloch[1], and Christoph Gohle[1,3] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Department of Physics, Temple University, Philadelphia, USA — [3]Ludwig-Maximilians-Universität, München, Germany

Quantum gases of polar molecules allow for dipolar interactions in quantum simulation. They have large dipole moments at long lifetimes, which make them ideal for realizing long range physics beyond nearest neighbor interactions.

The rotational degree of freedom of molecules can be used to encode spins. Due to the different parity of ground and first excited rotational state their polarizabilities at optical frequencies can however differ significantly, which leads to decoherence in an optical dipole trap. The polarization of the trapping field can be used to tune this difference and even to achieve a magic condition, where it is zero. Then long coherence times between the two states should be achievable.

We experimentally explore the first excited rotational state manifold of fermionic NaK using microwave spectroscopy. We demonstrate how small static electric fields can be used to decouple nuclear spin and molecular rotation and thus to simplify the complex rotational state spectrum and allowing an even longer coherence time. We characterize the molecular polarizabilities in a 1550 nm 1D lattice and investigate physics around the magic angle.

Q 62.29 Thu 16:15 Redoutensaal

A 3D Optical Lattice for the Creation of a Dense, Ultracold 23Na40K Gas — •Scott Eustice[1], Xin-Yu Luo[1], Frauke Seesselberg[1], Immanuel Bloch[1,2], and Christoph Gohle[1] — [1]Max-PlanckInstitut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany

We present the implementation of a 3D optical lattice for the production and trapping of ultracold, ground state 23Na40K molecules. Dipolar molecules can explore long-range interacting physics and the implementation of a lattice allows new regimes to be entered.

NaK molecules are created by mixing samples of Na and K, creating weakly bound Feshbach molecules, and then using STIRAP to transfer the Feshbach molecules into their ground state.

Creating large samples of NaK molecules depends on achieving a near unity filling factor of the initial Na and K atomic samples. Loading the fermionic K into the lattice is expected to give an 85% filled band insulator of 40.000 atoms. Too many bosonic Na atoms leads to greater than unity fillings, preventing molecule association. The low mass of Na compared to other bosonic atoms means that a large, unity filling Mott insulator can be created. For our experiment, we expect to obtain a 95% filled Mott insulator of 40.000 Na atoms.

With these samples, we expect Feshbach association efficiency to improve from 10% to near 100% in the lattice. We expect to achieve a final sample of 25.000 ground state NaK molecules at 60% filling, a significant improvement over previous results.

Q 62.30 Thu 16:15 Redoutensaal

Atom-chip-based interferometry with Bose-Einstein condensates — •Martina Gebbe[1], Matthias Gersemann[2], Sven Abend[2], Sven Herrmann[1], Claus Lämmerzahl[1], Ernst M. Rasel[2], and The QUANTUS Team[1,2,3,4,5,6] — [1]ZARM, Uni Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Atom interferometry is a well-proven tool to measure inertial forces or fundamental constants with high accuracy. Bose-Einstein condensates (BECs) or delta-kick collimated (DKC) atoms present ideal sources for precise measurements due to their small spatial and momentum width. We generate such an ensemble in a miniaturized atom-chip setup, where BEC generation and DKC can be performed fast and reliably. We present new results on our atom-chip-based gravimeter, which takes place in a volume of a one centimeter cube and comprises an innovative fountain scheme to enhance the device's sensitivity. The relaunch mechanism consists of the combination of double Bragg diffraction with Bloch oscillations. The same techniques are employed in our symmetric scalable large momentum beam splitters, which can be used in long baseline interferometry. This work is supported by the CRC 1128 geo-Q and by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. DLR 50WM1552-1557 (QUANTUS-IV-Fallturm).

Q 62.31 Thu 16:15 Redoutensaal

Autonomous control of a laser system for dual-species atom interferometry on board a sounding rocket — •Benjamin Wiegand[1,6], Klaus Döringshoff[1], Oliver Anton[1], Simon Kanthak[1], Markus Krutzik[1,2], Achim Peters[1,2], and The Maius team[1,2,3,4,5] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Physik, JGU Mainz — [5]IQO, Leibniz Universität Hannover — [6]LMU München

The MAIUS 2/3 missions aim for high-precision tests of Einstein's Equivalence principle by means of dual-species atom interferometry (AI) with BEC's of rubidium and potassium on a sounding rocket. While this platform features long microgravity times, it puts high demands on the compactness, robustness and agility of the experiment and requires a concept for autonomous operation.

In this poster, we present a laser system based on micro-integrated diode lasers that is designed for cooling, state preperation and simultaneous Raman double-diffraction interferometry to probe for differential accelerations. We report in detail on our concept for autonomous and agile frequency control of phase-locked extended cavity diode lasers (ECDL) in a dual-use configuration for laser cooling and Raman interferometry. Furthermore, we present results of environmental and performance tests of the laser system.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WP1432.

Q 62.32 Thu 16:15 Redoutensaal

A robust laser system for atom interferometry with rubidium on very long baselines — •Dorothee Tell, Christian Meiners, Etienne Wodey, Dennis Schlippert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Germany

The Very Long Baseline Atom Interferometer (VLBAI) introduces a new scale of ground-based interferometers employing ultra-cold atoms on a 10 m baseline, enabling absolute measurements of gravity and its gradients with unprecedented precision and macroscopic separations of superposition states. Long distances and interferometry times pose a challenge to all the components to avoid technical limitations, questioning the scalability of known methods and constraints.

Demands on the laser system for rubidium atom interferometry comprise well-chosen seed laser frequencies, the flexibility to implement a cooling scheme ensuring low expansion rates of the atomic ensembles, and high power in large interferometry beams to reduce wavefront induced phase shifts and enable large momentum transfer beam splitters.

We will present a robust laser system relying on well established telecommunication technology at 1560 nm allowing low-noise lasers and high-power amplifiers, and using flexible single-pass second harmonic generation to create light around the rubidium D_2 transition frequency.

The VLBAI facility is a major research equipment funded by the DFG. We acknowledge support from the CRCs 1128 "geo-Q" and 1227 "DQ-mat".

Q 62.33 Thu 16:15 Redoutensaal

Quantum optics on the ISS — •Kai Frye[1], Dennis Becker[1], Christian Schubert[1], Thijs Wendrich[1], Ernst Maria Rasel[1], and BECCAL Team[1,2,3,4,5,6] — [1]LU Hannover — [2]U Ulm — [3]FBH Berlin — [4]U Berlin — [5]U Mainz — [6]ZARM at U Bremen

BECCAL will be an important milestone for the ongoing quest of further advancing quantum optics into space. A multi-user and - purpose facility will be launched to the International Space Station to perform a large variety of experiments with ultracold Rb and K atoms, therefore providing an extraordinary platform in a permanent microgravity environment.

Building upon the heritage of the MAIUS sounding rocket mission, which created the first Bose-Einstein-Condensate in space, German and American scientists jointly proposed research topics including the production of dual-species BECs, atom interferometry, ultra-cold quantum mixtures, shell geometries and spinor gases.

Our poster sketches the preliminary concepts and architecture, including the dimensions and estimated capabilities of the setup. Some crucial and newly developed components, such as a compact and robust tip-tilt mirror setup, will be presented in detail.

The BECCAL project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under the grant numbers 50WP1431 and 50WP1700.

Q 62.34 Thu 16:15 Redoutensaal

Novel techniques for atom interferometry — •Dennis Schlippert[1], Henning Albers[1], Claus Braxmaier[2], Felipe Guzmán[2], Lee Kumanchik[2], Dipankar Nath[1], Logan Richardson[1], Simon Rossmann[1], Christian Schubert[1], Ashwin Thennadil[1], Wolfgang Ertmer[1], and Ernst Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]DLR Institut für Raumfahrtsysteme, Bremen

Today's state-of-the-art atom gravimeters require improvements in stability and accuracy in order to fully exploit their potential with large scale factors on very long baselines on ground and in space. Here we report on work towards improving the accuracy of our Rb-K-interferometer by means of a time-averaged optical dipole trap. Dynamically shaping the potential allows one to increase the initial trap volume as well as the evaporation efficiency. Likewise, the potential can be adapted for common δ-kick collimation of the dual species ensemble, eliminating a leading systematic uncertainty and improving the contrast. Moreover, we employ a novel class of highly compact opto-mechanical inertial sensors for postcorrection of seismic noise, otherwise limiting the short term stability of the atom interferometer. We show first demonstration experiments as well as future directions for broad applications of hybrid systems.

The presented work is supported by CRC 1128 geo-Q, the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) (Grant No. 50WM1641), and through the Quantum- and Nano-Metrology (QUANOMET) initiative.

Q 62.35 Thu 16:15 Redoutensaal

Gravity sensing with Very Long Baseline Atom Interferometry — •Etienne Wodey[1], Manuel Schilling[2], Christian Meiners[1], Dorothee Tell[1], Dennis Schlippert[1], Christian Schubert[1], Ludger Timmen[2], Wolfgang Ertmer[1], Jürgen Müller[2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Erdmessung, Leibniz Universität Hannover

Very Long Baseline Atom Interferometry (VLBAI) represents a new generation of atom interferometry based sensors aiming at measuring inertial forces and performing tests of fundamental physics with unprecedented resolution and accuracy. An extension of the baseline from tens of centimeters to over ten meters combined with novel seismic noise reduction systems puts sensitivities competing with those of superconducting gravimeters within reach, while keeping the stability and accuracy inherent to atomic sensors. Among other applications, next generation gravity reference stations can then be envisaged.

However, performing high-accuracy atom interferometry over such extended baselines poses severe challenges to the design of the apparatus. We focus in particular on our strategies to control magnetic and gravity fields along the baseline as well as reduce the seismic noise of the inertial reference. We also present the development of our source of ultracold ytterbium atoms which, thanks to its rich energy levels structure and outstanding magnetic properties in its electronic ground state opens further prospects for high-performance atom interferometry.

This work is supported by the CRCs 1128 geo-Q and 1227 DQ-mat.

Q 62.36 Thu 16:15 Redoutensaal

Automated control-electronics for a dual species atom interferometer on a sounding rocket. — •Wolfgang Bartosch, Thijs Wendrich, Ernst Maria Rasel, and Wolfgang Ertmer — Institut für Quantenoptik, Universität Hannover

Interferometry experiments with ultra-cold degenerate quantum gases under microgravity conditions offer possibilities to test fundamental laws of physics to unprecedented precision. The MAIUS-2/3 sounding rocket missions is planned to explore dual species atom interferometry in space. Operation on sounding rockets poses strict requirements on the mass, volume, on features like reliability and robustness of the payload and the system needs to operate autonomously. Based on our experience from the predecessor mission MAIUS-1, we improved our electronics to match the needs of a mission with two species. We had to further downsize the electronic components to fit hardware for a second species in an experiment the same size. Also we had to improve our systems to deal with the various challenges that arose from the results of the MAIUS-1 mission. In this poster we present our progress on this work.

The QUANTUS/MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number: 50WP1431.

Q 62.37 Thu 16:15 Redoutensaal

Operating a mobile Gravimetric Atom Interferometer GAIN at the fundamental station Wettzell — •Anne Stiekel[1], Bastian Leykauf[1], Vladimir Schkolnik[1], Christian Freier[1], Hartmut Wziontek[2], Axel Rülke[2], Markus Krutzik[1], and Achim Peters[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Germany — [2]Bundesamt für Karthographie und Geodäsie

GAIN is an atomic interferometer based on rubidium and stimulated Raman transitions used to measure the gravitational acceleration. Its transportability makes it possible to measure at sites of geodetic and geophysical interest.

In cooperation with the German Federal Agency for Cartography and Geodesy (Bundesamt für Karthographie und Geodäsie, BKG) a measurement campaign was conducted at the geodetic observatory in Wettzell to show the performance of quantum gravity sensor.

We will show the experimental apparatus and the operation with a focus on beam alignment. New procedures were tested to adjust the setup and thus optimize the measurement.

A long-term gravity measurement was recorded and compared with a superconducting gravimeter. We will discuss the Coriolis effect and a strategy to suppress the resulting phase shift. Another objective was to analyse the effect of an active and passive vibration isolation as well as the efficiency of a post-correction.

Q 62.38 Thu 16:15 Redoutensaal

Tackling leading order uncertainties in atom gravimetry — •Nina Grove, Maral Sahelgozin, Jonas Matthias, Jan Philipp Barbey, Sven Abend, Waldemar Herr, and Ernst M. Rasel — Inst. f. Quantenoptik, Leibniz Universität Hannover

On our poster we will discuss the limiting systematic effects in state-of-the-art atom gravimeters and present our estimations for mitigating these uncertainties in our novel transportable Quantum Gravimeter QG-1. The improved performance will be made possible by employing magnetically lensed Bose-Einstein Condensates as the source for the atom interferometer, as the current generation of atom gravimeters are limited by the use of thermal laser cooled atomic ensembles. By this the leading systematic error caused by wavefront aberrations and the Coriolis force will be suppressed. Approaching an accuracy of 10^{-9}m/s^2 novel contributions to the uncertainty budget, namely shifts due to mean field energy and the Black Body Radiation, will be discussed. This work is supported by the Deutsche Forschungsgemeinschaft (DFG) as part of project A01 within the SFB 1128 geo-Q.

Q 62.39 Thu 16:15 Redoutensaal

Coherent beam combination and power actuation of high power lasers for gravitational wave detectors — Nina Bode and •Benno Willke — Max Planck Institute for Gravitational Physics, Hannover

The next generation of gravitational wave detectors, like the Einstein Telescope, are designed to reach a high sensitivity at a broad range of frequencies. At high frequencies shot noise is a fundamental limit. As the shot noise limited sensitivity improves with increasing laser power it is proposed to use a 500W laser source with a wavelength of 1064 nm.

Currently available laser sources with such a high power do not fulfill the strong power, frequency and mode stability requirements of gravitational wave detectors. The coherent beam combination of two stable 250W lasers could generate a 500W beam with the required stability.

For demonstration purposes we performed a coherent beam combination of two solid-state laser systems, at a wavelength of 1064nm, with a combination efficiency of 90%.

To handle the high power beams, we developed a fast power actuator working with the effect of frustrated total internal reflexion (FTIR).

The FTIR-actuator produces a reflected and transmitted beam, the power ratio of wich can be adjusted. We characterized the reflected and transmitted beam and found that the actuator does not signifancantly influence the spatial beam shape and the noise of both beams.

Q 62.40 Thu 16:15 Redoutensaal

Progress Towards an Al$^+$ Quantum Logic Optical Clock — Nils Scharnhorst[1,2], •Johannes Kramer[1], Ian D. Leroux[1], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

We present the status of our aluminum ion optical clock, based on a single ^{27}Al$^+$ clock ion confined in a linear Paul trap together with a ^{40}Ca$^+$ logic ion. The latter is used for sympathetic cooling and internal state detection of the clock ion via the Coulomb interaction. ^{27}Al$^+$ provides a narrow (8 mHz) clock transition at 267 nm which exhibits negligible electric quadrupole shift and an exceptionally low sensitivity to black-body radiation. A measurement of the trap temperature combined with numerical simulations allows us to bound the black-body radiation shift to $< 10^{-19}$. Micromotion has been compensated to a level well below a fractional frequency uncertainty of 10^{-17}. We developed double-bright electromagnetically induced transparency (D-EIT) cooling [1] as novel scalable approach to standard EIT cooling. Using the D-EIT scheme we demonstrated for the first time ground-state cooling of all three motional degrees of freedom of a trapped ^{40}Ca$^+$ ion within a single, short cooling pulse [1]. Our next step is to extend this technique to ground-state cooling of all six motional modes of an Al-Ca crystal. Extrapolating from the results of a single Ca$^+$ cooling, we expect a fractional second order Doppler shift from residual motion of well below 10^{-18}. [1] Scharnhorst et al., arXiv: 1711.00732v2 (2017)

Q 62.41 Thu 16:15 Redoutensaal

Towards a transportable ^{27}Al$^+$ quantum logic optical clock — •Lennart Pelzer[1], Stephan Hannig[1], Mariia Stepanova[1], Johannes Kramer[1], Nils Scharnhorst[1], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

According to Einstein's theory of relativity, optical clocks tick slower near a gravitating body. On Earth, this corresponds to a fractional frequency change of 10^{-17} for 10 cm height difference. Clock comparisons via length-stabilized optical fibers thus enable height difference measurements over long distances, realizing "relativistic geodesy" with clocks. Such measurements complement classical techniques base on spirit leveling or a combination of gravimetry and satellite positioning.

We present the status of our ^{27}Al$^+$/ ^{40}Ca$^+$ quantum logic optical clock. An Al$^+$ ion serves as the clock ion with a narrow (8mHz) transition at 267nm which is insensitive to electromagnetic line shifts. The single Al$^+$ ion is confined together with a single Ca$^+$ ion. The latter is used for sympathetic cooling to the ground state as well as the readout of the clock transition. We present a transportable setup in which many optics components are fiber-coupled. Using ablation loading we can trap single Ca$^+$ ions in a segmented linear Paul trap with low heating rate and small black-body radiation shift. We present first results on ground state cooling and trap characterization. The setup will be transferred into a container to demonstrate relativistic geodesy at a level of 10 cm and below.

Q 62.42 Thu 16:15 Redoutensaal

Towards a test of Local Lorentz Symmetry with ^{172}Yb$^+$ ions — •Chih-Han Yeh, André P. Kulosa, Alexandre Didier, Dimitri Kalincev, Jan Kiethe, Tabea Nordmann, Nimrod Hausser, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38166 Braunschweig, Germany

We report on an experiment to be carried out with two entangled ^{172}Yb$^+$ ions which tests the Local Lorentz Invariance (LLI) in the electron-photon sector. The relevant states we use for the LLI test are the $4f^{13}6s^2\ ^2F_{7/2}$ ($m_J = |1/2|$ and $m_J = |7/2|$) substates that have orthogonal orientations which respond differently to the Lorentz-violating effect quantified by the $c'_{\mu\nu}$ tensor. This will cause the energy difference between them to change as the Earth rotates with respect to the Sun-centered frame. The ions must be prepared in a decoherence-free subspace before being mapped onto the $^2F_{7/2}$ state, since magnetic field noise will destroy the ions' state coherence. The entanglement in the $^2F_{7/2}$ state can be prepared in three theoretically promising ways: 1. via Mølmer Sørensen Gate; 2. preparing a product state which dephases into a mixed state[1]; 3. using two-frequency bichromatic laser to map the ions directly onto the $^2F_{7/2}$ state[2].

Currently we are setting up the 934nm laser which will be frequency doubled into a 467nm laser for interrogation of the octupole transition in ^{172}Yb$^+$.

[1] T. Pruttivarasin et al., *Nature* **517**, 592-595 (2015).
[2] V. A. Dzuba et al., *Nature Physics* **12**, 465-468 (2016).

Q 62.43 Thu 16:15 Redoutensaal

48 cm long ultra-stable glass resonator with crystalline mirror coatings — •Steffen Sauer[1], Steffen Rühmann[1], Dominika Fim[1], Klaus Zipfel[1], Nandan Jha[1], Waldemar Friesen-Piepenbrink[1], Rasmus Holst[1], Sebastian Häfner[2], Thomas Legero[2], Wolfgang Ertmer[1], Uwe Sterr[2], and Ernst Rasel[1] — [1]Institut für Quantenoptik, Hannover, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Ultra-stable lasers are one of the key components utilized in optical frequency standards for probing ultra-narrow transitions. Currently, the ultimate frequency stability of resonators is limited by the thermal noise of the mirror coating. To reduce the resulting frequency instability we are setting up a resonator of 48 cm length with crystalline mirror coatings [Cole et al., Nat. Phot. **7**, 644 (2013)]. This leads to a low Brownian noise floor with a calculated fractional frequency instability of 3×10^{-17} which is competitive to cryogenic optical resonators. The system is built in cooperation with the PTB following the design in [Häfner et al., Opt. Lett. **40**, 2112 (2015)]. The resonator will be characterized against the single-crystal silicon resonators at PTB and will be used as ultra-stable local oscillator for the magnesium lattice clock experiment at IQ, Hannover. A frequency comb will transfer the frequency stability of the long resonator at 1560 nm to our current clock laser system at 916 nm, which is limited at 4×10^{-16} in 1 s. The lower frequency noise will lead to longer interrogation time, which will reduce the noise contribution of the Dick effect. We report on the progress and performance of our ultra-stable laser system.

Q 62.44 Thu 16:15 Redoutensaal

An optical lattice clock based on Magnesium — •Waldemar Friesen-Piepenbrink, Dominika Fim, Klaus Zipfel, Steffen Rühmann, Nandan Jha, Steffen Sauer, Wolfgang Ertmer, and Ernst Rasel — Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We present the current status of our optical lattice clock based on the strongly forbidden $^1S_0 \rightarrow ^3P_0$ transition in the bosonic ^{24}Mg isotope. With its small black body radiation sensitivity, magnesium is a promising candidate for an optical frequency standard.

We are able to load 10^4 precooled bosonic magnesium atoms into an optical lattice at the magic wavelength. Due to its low mass, a high trap depth is required to significantly suppress tunneling between adjacent lattice sites and minimize the resulting linewidth for spectroscopy. At a trap depth of 50 E_{Recoil} we were able to perform spectroscopy of a 50 Hz linewidth with the highest Q value for magnesium. Together with an improved magnetic field setup, necessary for magnetic field induced spectroscopy, we were able to characterize the systematics of the clock with an uncertainty in the 10^{-15} regime.

We will give an outlook of our efforts towards further reduce the linewidth of our magnesium clock.

Q 62.45 Thu 16:15 Redoutensaal

Operating a high-accuracy lattice optical clock with a filtered tapered amplifier lattice laser — •Pramod Mysore Srinivas[1], Stefano Origlia[1], Stephen Schiller[1], Christian Lisdat[2], Uwe Sterr[2], Jürgen Stuhler[3], Stefan Baumgärtner[3], and Rudolf Neuhaus[3] — [1]Institut für experimentalphysik, Heinrich Heine Universität, 40225, Düsseldorf, Germany — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, Braunschweig, Germany — [3]Toptica Photonics AG, Lochhamer Schlag 19, 82166,Gräfelfing, Germany

In an optical lattice clock atoms are trapped and interrogated in a periodic potential generated using a strong light field (optical lattice). A shift of the clock transition frequency can be strongly suppressed by operating the lattice laser at the *magic* frequency. A high spectral purity of the lattice beam is also of critical importance for minimizing residual shifts. In tapered amplifier (TA) diode lasers the contribution of amplified spontaneous emission (ASE) is a major limiting factor for achieving clock uncertainty below 1x10-16. In this work we present the characterization of a new grating-based filter to suppress the ASE of a commercial 813 nm laser in a transportable Sr clock [1]. Its magic wavelength is compared with the one of a Ti:Sapphire laser. The optical clock frequency uncertainty due to the lattice laser is evaluated.
[1] Origila et al. Proc. of SPIE 9900, 990003-1 (2016)

Q 62.46 Thu 16:15 Redoutensaal

Non-magnetic setup for an Indium multi-ion clock — •Tabea Nordmann, Hartmut Nimrod Hausser, Alexandre Didier, Jan Kiethe, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Optical ion clocks are one of the most promising candidates to approach fractional uncertainties of 10^{-18} and below. Using N ions instead of a single ion shortens the interrogation time to reach that level by a factor 1/N compared to the latter.

In the past years we have successfully developed a new ion trapping platform which is capable of trapping ion crystals in a well-controlled environment on that accuracy level.

Here we present our new experimental apparatus for a multi-ion clock based on $^{115}In^+$ ions which are sympathetically cooled with $^{172}Yb^+$ ions in a mixed linear ion crystal.

Apart from the segmented AlN trap the new setup consists of a non-magnetic and low outgassing titanium vacuum chamber with a variety of laser access and magnetic field coils providing a B-field with estimated inhomogeneities below 15nT over the whole trapping area.

Furthermore, we discuss the laser systems for addressing the cooling and detection transition in indium ($^1S_0$ to $^3P_1$), operating at 230.6nm.

The read-out of the clock is based on simultaneously imaging both ion species on one EMCCD camera by two aspheric lenses.

Photonic crystal fibers are tested as a mode cleaner for the deep UV light at 230.6nm and 236.5nm for exciting the clock transition ($^1S_0$ to $^3P_0$).

Q 62.47 Thu 16:15 Redoutensaal

Interrogating optical clocks beyond the coherence limit of the clock laser — •Roman Schwarz[1], Ali Al-Masoudi[1], Sören Dörscher[1], Marcin Bober[2], Richard Hobson[3], Uwe Sterr[1], and Christian Lisdat[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziadzka 5, 87-100 Torun, Poland — [3]National Physical Laboratory, Hampton Road, Teddington, Middlesex, UK, TW11 0LW

The performance of optical clocks benefit from ultra stable laser systems enabling several seconds of interrogation time. For longer interrogation times, the coherence time of the clock laser becomes one limiting factor. Even with state-of-the-art laser systems, the natural linewidth of the clock transition has not been reached yet. Here we present a novel interrogation method, which allows interrogation times beyond the coherence time of the laser. The proposed technique utilizes a correlated interrogation sequence of two atomic clocks with a single clock laser to resolve the phase ambiguity occurring for Ramsey interrogation beyond the coherence limit of the interrogation laser. Additionally, probing the atomic ensemble for several seconds, effects such as Raman scattering induced by the intense optical lattice may cause a frequency shift and limit the coherence time. This work is supported by QUEST, the DFG within CRC 1128 (geo- Q A03), CRC 1227 (DQ-mat B02) and RTG 1729.

Q 62.48 Thu 16:15 Redoutensaal

Twisted-light–ion interaction: the role of longitudinal fields — Guillermo. F. Quinteiro[1], Christian. T. Schmiegelow[1], and •Ferdinand Schmidt-Kaler[2] — [1]Departamento de Fisica and IFIBA, FCEN, Universidad de Buenos Aires, Ciudad Universitaria, Pabellon I, 1428 Ciudad de Buenos Aires, Argentina — [2]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

The propagation of light beams is well described using the paraxial approximation, where field components along the propagation direction are usually neglected. For strongly inhomogeneous or shaped light fields, however, this approximation may fail, leading to intriguing variations of the light-matter interaction. This is the case of twisted light having opposite orbital and spin angular momenta. We compare experimental data for the excitation of a quadrupole transition in a single trapped Ca+ ion [1] with a model where longitudinal components of the electric field are taken into account. Our model matches the experimental data and excludes by 11 standard deviations the approximation of complete transverse field [2]. This demonstrates the relevance of all field components for the interaction of twisted light with matter.

[1] Schmiegelow et al, Nat. Comm. 7, 12998 (2016)
[2] Quinteiro, Schmiegelow and Schmidt-Kaler, arXiv 1709.05571

Q 62.49 Thu 16:15 Redoutensaal

Dynamics in quantum metrology — •Lukas J. Fiderer and Daniel Braun — Universität Tübingen, Germany

The typical protocol of a quantum measurement starts with state preparation followed by dynamics that encode the parameter to be measured to the system and ends with a readout by measuring the quantum state which allows to infer the parameter. System size N and the time t, that the system evolves before it is measured, are crucial resources that determine the performance of the measurement. Measurement precision scales under "classical" conditions with $1/(\sqrt{N}T)$, called standard quantum limit (SQL). It is well known that this limit can be beaten by preparing initial quantum states that are entangled, when SQL is replaced by the Heisenberg scaling $1/(NT)$. While a lot of research centres around finding beneficial entangled states to eventually beat SQL such quantum states are typically difficult to prepare and prone to decoherence. We present possibilities to improve quantum measurements under experimental feasible conditions with easily accessible, classical states. With the help of the quantum Fisher information we investigate novel types of dynamics to encode the parameter to the system. Realistic simulations prove the suitability for application in magnetic field sensors.

Q 62.50 Thu 16:15 Redoutensaal

Setup for the measurement of stress-induced optical birefringence — •Jan Meyer[1,3], Johannes Dickmann[1], Rene Glaser[2], Carol Bibiana Rojas Hurtado[1], Walter Dickmann[1,3], and Stefanie Kroker[1,3] — [1]Physikalisch-Technische Bundesanstalt Braunschweig, Bundesallee 100, Braunschweig, Germany — [2]Friedrich-Schiller-Universität Jena, Institut für Festkörperphysik, Helmholtzweg 5, Jena, Germany — [3]Technische Universität Braunschweig, LENA Laboratory for Emerging Nanometrology,Pockelsstraße 14, Braunschweig, Germany

Optomechanical systems for high-precision sensing such as optical ring resonators or gravitational wave detectors require a detailed knowledge of mechanical and optical material parameters.

We introduce a versatile setup for the dynamic measurement of optical and mechanical properties, for example of mechanical loss, birefringence and elastic tensors. To perform frequency dependent (resonant and off-resonant) investigations we drive the samples by piezo-electric actuators or strong quasi-electrostatic fields. The mechanical motion of the sample is monitored by a fringe-locked Michelson Interferometer based on a stabilized 632 nm HeNe-Laser. To measure the dynamically induced birefringence we couple the setup to a tunable light source (300 nm...2000 nm) based on a Czerny-Turner monochromator that can be flexibly connected to either an ellipsometer or Mach-Zehnder interferometer.

Q 62.51 Thu 16:15 Redoutensaal

High frequency precision quantum metrology — •Nicolas Staudenmaier[1], Simon Schmitt[1], Liam P. McGuinness[1,2], and Fedor Jelezko[1,2] — [1]Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, Ulm 89081, Germany — [2]Center for Integrated Quantum Science and Technology, Ulm University, Albert-Einstein-Allee 11, Ulm 89081, Germany

Due to their small size and high sensitivity, nitrogen vacancy centers in diamonds are excellent sensors for nanoscale nuclear and electron magnetic resonance experiments. Recently, detection of single molecules and the study of their structure and dynamics has been demonstrated. A crucial point for single molecule spectroscopy is the spectral resolution. It was shown that the spectral precision of NV magnetometry can exceed the sensor coherence time and is only limited by the clock stability of an external oscillator [1]. While previous experiments were restricted to measure frequencies up to a few MHz, here we present and discuss a new technique which extends the measurement range to high frequency fields. The new technique we demonstrate allows detection of a GHz magnetic field with sub-Hz linewidth, using a quantum coherent sensor.

[1] Simon Schmitt et al. "Submillihertz magnetic spectroscopy performed with a nanoscale quantum sensor." Science 356 (2017): 832-837

Q 62.52 Thu 16:15 Redoutensaal

Towards ultrasensitive mass sensing using single spins in diamond — •Tetyana Shalomayeva[1], Thomas Oeckinghaus[1], Ali Momenzadeh[1], Dominik Schmid-Lorch[1], Durga Dasari[1,2], Amit Finkler[3], Rainer Stöhr[1], and Jörg Wrachtrup[1,2] — [1]3rd Institute of Physics, University of Stuttgart — [2]Max Planck Institute for Solid State Research — [3]Department of Chemical and Biological Physics Weizmann Institute of Science

Quantum sensing has emerged recently as the breakthrough application of spin defects in solids. In this regard, negatively-charged nitrogen vacancy centers (NV) in diamond are presented as ultrasensitive sensors of magnetic field [1], electric field [2], temperature [3], stress and pressure [4,5], and force [6]. Here, ultrasensitive measurement of mass employing NV centers as embedded nanosensors in diamond micromechanical oscillators is discussed. Different techniques such as optical readout of the oscillator position and ODMR-based measurements are analytically discussed and compared. This is followed by a demonstration of the experimental realization of the platform and mass-sensing results.

[1] G. Balasubramanian et al. Nature 455, 648-651 (2008) [2] F. Dolde et al. Nature Physics 7, 459-463 (2011) [3] P. Neumann et al. Nano Lett., 2013, 13 (6), pp 2738-2742 [4] J. Teissier et al. Phys. Rev. Lett. 113, 020503 (2014) [5] S. A. Momenzadeh et al. Phys. Rev. Applied 6, 024026 (2016) [6] M. S. J. Barson et al. Nano Lett., 2017, 17 (3), pp 1496-1503

Q 62.53 Thu 16:15 Redoutensaal

Coarse-grained master equation for an optical dense atomic ensemble — •Aleksei Konovalov, Andreas Alexander Buchheit, and Giovanna Morigi — Saarland University, 66123 Saarbrücken

We apply the coarse-graining method to derive a master equation of an ensemble of atoms interacting with the electromagnetic field. For a single atom such master equation naturally includes terms due to quantum interference in the decay channels and fulfills the requirements of the Lindblad theorem without any phenomenological assumptions (see Phys. Rev. A 94, 042111 (2016)). An extension of this theoretical approach for describing the atomic emission behavior of an ensemble of atoms requires taking into account the interaction between the atoms, thus also quantum interference due to dipole-dipole interactions at different transition frequencies. We discuss the effect that these additional terms can have on light propagation in an optically dense medium.

Q 62.54 Thu 16:15 Redoutensaal

Collective hyperfine splitting in resonant x-rays scattering — •Xiangjin Kong and Adriana Pálffy — Max Planck Institute for Nuclear Physics, 69117 Heidelberg,Germany

In an ensemble of identical atoms, cooperative effects like superradiance may alter the decay rates and the transition energies may be shifted from the single-atom value by the so-called collective Lamb shift. While such effects in ensembles of two-level systems are well understood, realistic multi-level systems are more difficult to handle. Mössbauer nuclei in x-ray thin-film cavities are a clean quantum optical system in which the collective Lamb shift has been observed [1].

Here, we present a quantitative study of systems of ^{57}Fe nuclei under the action of an external magnetic field, where a collective contribution to the level shifts appears that can amount to seizable deviations from the single-atom magnetic hyperfine splitting. We develop a formalism to describe single-photon superradiance in multi-level systems and identify three parameter regimes, two of which present measurable deviations in the radiation spectrum compared to the case of single-nucleus magnetic-field-induced splitting [2]. All three regimes should be realizable in planar x-ray cavities with an embedded nuclear layer under experimental parameters available today.

[1] R. Röhlsberger *et al.*, Science 328, 1248 (2010).
[2] X. Kong and A. Pálffy, Phys. Rev. A 96, 033819 (2017).

Q 62.55 Thu 16:15 Redoutensaal

Polaritonic Contribution to the Casimir Interaction in Graphene Systems — •Christoph Egerland[1,2], Francesco Intravaia[2], and Kurt Busch[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

The Casimir effect is a phenomenon where two uncharged bodies placed in vacuum attract each other due to quantum or thermal fluctuations. In addition to its fundamental interest, the Casimir force also has important technological implications, since it can cause sticking or jamming between parts of nanodevices. To control these (often unwanted) effects, one can leverage on the so-called surface polaritons, i.e. material excitations living at the surface of the bodies. They indeed dominate the Casimir interaction in the limit of small separations. Recently, due to its prospective applications in nanotechnology, a lot of attention was devoted to the calculation of the Casimir force in graphene systems.

We examine in detail the contribution of the polaritonic modes to the Casimir interaction between two parallel layers of graphene. We put a special emphasis on the material model chosen to describe graphene and we consider some specific features such as a non-vanishing band gap.

Q 62.56 Thu 16:15 Redoutensaal

Proximity force approximation and specular reflection: application of WKB Mie scattering to the Casimir effect — •Benjamin Spreng[1], Michael Hartmann[1], Vinicius Henning[2], Paulo A. Maia Neto[2], and Gert-Ludwig Ingold[1] — [1]Universität Augsburg, Institut für Physik, 86135 Augsburg, Germany — [2]Instituto de Física, UFRJ, Rio de Janeiro, Brazil

The electromagnetic Casimir interaction between two spheres is studied within the scattering approach using the plane-wave basis. It is demonstrated that the proximity force approximation (PFA) corresponds to the specular-reflection limit of Mie scattering. Using the leading-order semiclassical WKB approximation for the direct reflection term in the Debye expansion for the scattering amplitudes, we prove that PFA provides the correct leading-order divergence for arbitrary materials and temperatures in the sphere-sphere and the plane-sphere geometry.

Q 62.57 Thu 16:15 Redoutensaal

Towards chiral cavity quantum electrodynamics with ensembles of atoms around an optical nanofiber — •Aisling Johnson, Martin Blaha, Alexander Ulanov, Philipp Schneeweiss, and Arno Rauschenbeutel — TU Wien - Atominstitut, Stadionallee 2, 1020 Wien

Interfacing atoms with light propagating through an optical nanofiber is a promising method for the study of light-matter interaction. We are currently developing an experiment based on such a nanofiber to probe new regimes of cavity quantum electrodynamics (cQED). The tapered nanofiber, including the 500 nm thick waist, is connected to a fiber ring resonator. By creating a MOT cloud around the waist, we can couple an ensemble of atoms to the cavity field which propagates as an evanescent field in this region where the cross-section of the fiber is smaller than the wavelength of light. Notably, the polarization properties of light in the tapered fiber can lead to chiral, i.e propagation-direction dependent, light-matter interaction, which is expected to strongly affect the collective behavior of the atomic cloud in the cavity field. In general this setup should lend itself well to novel cQED experiments as well as quantum simulation of strongly coupled light and matter.

Q 62.58 Thu 16:15 Redoutensaal

Optical Heterodyne Detection of a Cross-Phase Modulation Mediated by a Single Atom — •Jonas Neumeier, Nicolas Tolazzi, Bo Wang, Gang Li, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

Controlled interactions between individual photons are of fundamental interest. Cavity quantum electrodynamics in the regime of strong light-matter coupling provides a promising platform for implementing nonlinear interactions. In our experiment, two separate transitions of a four level atom in an N-type scheme are strongly-coupled to two distinct modes of a cavity that are driven by light fields at wavelengths 780 nm and 795 nm. A control laser induces coupling between these modes resulting in either mutual blocking or conjunct tunnelling of photons. Moving one of the modes to the dispersive regime makes non-destructive all-optical sensing of the photon number feasible [1]. It can be understood as the result of a photon number dependent Stark shift [2]. In addition, cross-phase modulation is expected: single photons present in one mode induce a significant phase shift on photons in the other mode. Recently, an optical heterodyne detection setup has been added to the experiment, making the measurement of this cross-phase modulation reachable. The setup combines analog downmixing with FPGA assisted data acquisition, offering direct digitization of both quadratures at a relatively low data rate.

[1]Schuster el al., Nature 445, 515-518 (2007)
[2]Albert et al., Nature Photonics 5, 633-636 (2011)

Q 62.59 Thu 16:15 Redoutensaal

Fiber-cavity-based single-photon single-atom interface — •Elvira Keiler, Wolfgang Alt, Jose Gallego, Tobias Macha, Deepak Pandey, Eduardo Urunuela, Jian Wang, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

We present our work on a photon-atom interface composed of an optical fiber-based Fabry-Pérot cavity and small ^{87}Rb ensembles. The small mode volume of fiber cavities allows us to remain in the strong coupling regime even for high cavity bandwidths. In this way, photon pulses even shorter than the atomic lifetime can be stored in the ensemble via stimulated Raman adiabatic passages. For this method, we calculate optimal pulse shapes [1] and generate them with a combination of fast arbitrary waveform generators and electro-optical modulators. Since the photon can be retrieved with the readout Raman pulse, the system realizes one of the building blocks necessary for quantum repeaters.

[1] Jerome Dilley, Peter Nisbet-Jones, Bruce W. Shore, and Axel Kuhn, Single-photon absorption in coupled atom-cavity systems, Phys. Rev. A 85, 023834 (2012).

Q 62.60 Thu 16:15 Redoutensaal

Strong Coupling between Photons via a four-level N-type atom — •Bo Wang, Nicolas Tolazzi, Jonas Neumeier, Christoph Hamsen, Gang Li, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Four-level N-type atomic systems have been investigated for effects like the electromagnetically induced absorption (EIA) and cross-phase modulation (XPM) when interacting with classical light fields[1]. Despite the giant nonlinearity, the interaction strengths are negligible at the level of individual quanta. However with the strong light matter coupling provided by cavity quantum elecrodynamics, a significant interaction between single photons can be reached. Here we report on an experiment where the photons of two light fields are strongly coupled via a single four-level N-type atom. The fields drive two modes of an optical cavity, which are strongly coupled to two separate transitions. A control laser drives one transition's ground state to the other transition's excited state, the inner transition of the N-type atom. It induces a tunable coupling between the modes and results in a doubly nonlinear energy-level structure of the photon-photon-atom system. The strong correlation between the light fields is observed via photon-photon blocking and photon-photon tunneling. With this new system, nondestructive counting of photons and heralded n-photon sources might be within reach.

[1]Li S, Yang X, Cao X, Zhang C, Xie C, Wang H, Phys. Rev. Lett. 101(7)(2008) 073602.

Q 62.61 Thu 16:15 Redoutensaal

Correlations between two coherently driven atoms in a cavity — •Marc-Oliver Pleinert[1,2,3], Joachim von Zanthier[1,2], and Girish Agarwal[3,4] — [1]Institut für Optik, Information und Photonik, FAU Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), FAU Erlangen-Nürnberg, 91052 Erlangen, Germany — [3]Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078, USA — [4]Institute for Quantum Science and Engineering and Department of Biological and Agricultural Engineering, Texas A&M University, College Station, Texas 77843, USA

The radiative behavior of ensembles of atoms in collective states, i.e., superradiance, has been studied in depth since the seminal paper by Dicke in 1954 (Phys. Rev. 93, 99), where he demonstrated that a group of entangled emitters is able to radiate with increased intensity and modified decay rates in particular directions. Here, we discuss the radiative characteristics and quantum properties of two coherently driven atoms coupled to a single-mode cavity, an ideal setup to investigate the basic aspects of collective behavior. We show that the system is able to exceed the free-space superradiant behavior of two atoms by orders of magnitude, a phenomenon which we call hyperradiance. We also study the phase control of the quantum statistics and find that a quantum version of the negative binomial distribution is able to characterize the photon distribution in the cavity and its quantum features. Our theoretical results could stimulate future experiments as the investigated system can be realized with current technology.

Q 62.62 Thu 16:15 Redoutensaal

Phases of cold atoms interacting via photon-mediated long-range forces — •Francesco Rosati[1], Tim Keller[1,2], Simon B. Jäger[1], and Giovanna Morigi[1] — [1]Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Okinawa Institute of Science and Technology Graduate University, Onna-son, Okinawa 904-0495, Japan

When directly pumping an atomic ensemble trapped in a crossed-cavities set up, atomic self-organization can occur via the interaction mediated by the photons. In this work we first derive a Fokker-Planck equation for simulating the atomic evolution in the semi-classical approximation assuming that the photons' time scale for reaching the steady state is much faster than the atomic one.

Then we numerically investigate how this system self-organise in the two cavities; moreover we show that in a two-mode standing-wave cavity the stationary state possesses the same properties and phases of the Generalized Hamiltonian Mean Field model in the canonical ensemble. This model has three equilibrium phases: a paramagnetic, a nematic, and a ferromagnetic one, which here correspond to different spatial orders of the atomic gas and can be detected by means of the light emitted by the cavities.

Q 62.63 Thu 16:15 Redoutensaal

CO_2 laser fabrication of mirrors for cavity QED — •Riccardo Cipolletti, Stefan Häussler, Andrea B. Filipovski, Max Deisböck, and Alexander Kubanek — Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany

Coupling of solid state quantum emitters to optical microresonators to improve the optical properties of the emitters is a highly innovative field bringing quantum technology applications into reach. For this purpose high quality cavities are crucial. In particular, to achieve high values for cooperativity and Purcell enhancement [1], we need to obtain high finesse and small mode volume.

We show fabrication of cavity mirrors in fused silica using ablation by a CO_2 laser. This method enables small surface roughness and radius of curvature, thus small scattering losses and mode volume. We obtain feedback on the quality and shape of our structures by the use of an interferometer.

[1] D. Hunger *et al* 2010 *New J. Phys.* **12** 065038

Q 62.64 Thu 16:15 Redoutensaal

High- quality- fiber- based microcavity for SiV^- color centers in diamond. — •Richard Waltrich[1], Stefan Häussler[1], Kerem Bray[2], Fedor Jelezko[1], Igor Aharonovich[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics and Center for Integrated Science and Technology, Ulm University, D-89081 Ulm, Germany — [2]School of Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, New South Wales 2007, Australia

For the realization of quantum repeaters, coherent systems are essential. In the last decades, defects in diamond, especially the negatively charged silicon vacancy center (SiV^-), drew attention due to exceptional optical properties. To overcome issues concerning low rates of spontaneous emitted photons, poor extraction efficiency out of the diamond material, as well as low quantum yield, coupling of the relevant optical dipole transition to the mode of a microcavity is one possibility.

We present a system, consisting of SiV^- centers, located in a thin diamond membrane, coupled to a fiber based microcavity. We aim for enhanced spontaneous emission rates, due to the Purcell effect.

Q 62.65 Thu 16:15 Redoutensaal

Adiabatic flux insertion: growing quantum Hall states of cavity Rydberg polaritons — •David Dzsotjan[1], Peter Ivanov[2], Fabian Letscher[1], Jonathan Simon[3], and Michael Fleischhauer[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern,Kaiserslautern, Germany — [2]Department of Physics, St. Kliment Ohridski University of Sofia, Sofia, Bulgaria — [3]Department of Physics and James Franck Institute, University of Chicago, Chicago, IL, USA

Fractional quantum Hall states, previously discovered in 2D electron gases in solid-state systems, exhibit an intriguing physical behaviour. We propose a scheme that enables to create such states * the so-called Laughlin states * inside a twisted optical ring resonator, using photons dressed with Rydberg interactions. Because of the cavity geometry, these Rydberg polaritons experience an artificial magnetic field leading to Landau levels. Interactions lead to a splitting of the many-body spectrum with gapped states at even fractional fillings. Our aim is to prepare the most stable one, the Laughlin state with filling 1/2 using the growing technique suggested in [1,2]. A key feature of the scheme is the controlled insertion of single photon and magnetic flux quanta into the cavity system. For the insertion of flux quanta we propose and analyze an adiabatic method for transferring external orbital angular momentum from classical light beams to the cavity photons by using light-matter interaction as a mediator. [1] F.Grusdt et al., PRL 113, 155301 (2014) [2] F. Letscher et al., PRB 91, 184302 (2015)

Q 62.66 Thu 16:15 Redoutensaal

X-ray cavity QED beyond the input-output formalism — •Dominik Lentrodt, Kilian P. Heeg, Christoph H. Keitel, and Jörg Evers — MPI für Kernphysik, Heidelberg

The input-output formalism has been one of the main theoretical models in cavity QED, since it allows to describe the atom-cavity dynamics in terms of a few constants, such as resonance energies and decay time scales of the cavity. This is invaluable in understanding the mechanisms behind experimental results, since the constants can be fitted to data. However, in particular in the bad cavity regime or when multiple cavity modes are involved in the dynamics, this method does not always yield a unique explanation of the underlying processes. Indeed the use of input-output formalism for loss-dominated cavities has been debated theoretically and spectroscopic experiments using x-ray cavities doped with Mössbauer nuclei have shown that heuristic extensions to the input-output formalism, such as additional phase shifts, are required in order to successfully model collective Lamb shifts in the system [1,2].

We employ a recently developed method that links ab-initio quantisation to the input-output formalism to predict x-ray spectra in the nuclei-cavity system from the cavity geometry. Within this formalism, the additional phase shifts can now be understood as a multi-mode interference effect, enabled by crucial differences to standard assumptions in the input-output model approach. [1] Röhlsberger, R. et al. (2010). Science, 328, 1248-1251. [2] Heeg, K. P. & Evers, J. (2015). Phys. Rev. A, 91, 063803.

Q 62.67 Thu 16:15 Redoutensaal

Coupling Silicon Vacancy centers in nanodiamond to open acess micro cavities — Andrea Filipovski, •Gregor Bayer, Olaf Zimmermann, and Alexander Kubanek — Institute for Quantum Optics, University of Ulm, Ulm, Germany

For applications such as quantum repeaters or quantum networks efficient spin-photon links are required. One promising system is the negatively charged silicon vacancy (SiV^-) center in diamond which has shown to preserve its good optical properties from bulk in nanodiamonds [1,2]. In order to achieve good coupling between photon field and emitter an optical resonator produced by focussed ion beam milling can be employed. Optimizing the ratio of quality factor over mode volume $\frac{Q}{V}$ is desirable for largest coupling. In our attempt we keep V as small as possible while sustaining a reasonably high Q . Open Fabry-Pérot cavities are particularly attractive since they are tunable and compatible with various emitters. This allows us to examine the interaction between photons and SiV^- centers in nanodiamonds and investigate coupling at cryogenic temperatures.

[1] U. Jantzen et. al., NJP, Vol. 18, 2016 [2] Rogers et. al., in preparation

Q 62.68 Thu 16:15 Redoutensaal

Towards the realisation of an atom trap in the evanescent field of a microresonator — •Luke Masters, Elisa Will, Michael Scheucher, Adele Hilico, Jürgen Volz, and Arno Rauschenbeutel — VCQ, Atominstitut, Stadionallee 2, 1020 Wien, Austria

Whispering-gallery-mode (WGM) resonators guide light by total internal reflection and provide ultra-high optical quality factors in combination with a small optical mode volume. Coupling a single atom to the evanescent field of a WGM microresonator thus allows one to reach the strong coupling regime [1]. Furthermore, such resonators provide chiral light-matter coupling which can be employed for realising novel quantum protocols [2] as well as nonreciprocal quantum devices [3]. However, trapping atoms in the evanescent field of such resonators has not yet been demonstrated, which severely limits the atom-resonator interaction time. We aim to trap single Rubidium atoms in the vicinity of a bottle-microresonator using a standing wave optical dipole trap which is created by retroreflecting a tightly focussed beam on the resonator surface [4]. In order to load atoms into the trap, we employ an FPGA-based electronics which allows us to react in 150 ns to an atom arriving in the resonator field and thus to switch on the dipole trap. We will present first characterisations of our trap and discuss methods for detecting and cooling the atoms in the resonator.

[1] C. Junge et al. Phys. Rev. Lett. 110, 213604 (2013), [2] I. Shomroni et al. Science 345, 903 (2014), [3] M. Scheucher et al. Science 354, 1577 (2016), [4] J. D. Thompson et al. Science 340, 1202 (2013).

Q 62.69 Thu 16:15 Redoutensaal

Classicalization of a scalar quantum field — •Marduk Bolaños, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen, Duisburg

We present a master equation describing the classicalization of a scalar quantum field. It is based on the back-action of measurements of the amplitude and conjugate momentum of the field.

We show how to solve the master equation using a functional representation of the state operator [1] and study its decoherence dynamics.

[1] R. Graham and H. Haken, Z. Physik A 234, 193 (1970).

Q 62.70 Thu 16:15 Redoutensaal

Bunching and antibunching from a single light source — •Stefan Richter[1], Sebastian Wolf[2], Joachim von Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany

We have measured the first [1] and second order correlation functions of the light spontaneously emitted from a two ion crystal. The experimental measured $g^{(2)}$ $(t = 0)$ shows bunched or antibunched light, depending on the angle of photon observation and the distance between both ions. The data are compared to a theoretical expectation for the correlation functions using a master-equation approach. In this calculations we take ion motion, the excitation laser power and direction of the driving laser beam into account as well as the observation angle. Future experiments with two detectors at different positions are discussed where again a spatial modulation is predicted [2]. We investigate the feasibility of such experiments under realistic experimental conditions.

[1] S. Wolf et al., Phys. Rev. Lett. **116**, 183002 (2016)

[2] C. Skornia et al., Phys. Rev. A **64**, 063801 (2001)

Q 62.71 Thu 16:15 Redoutensaal

N00N-like Interferences from two Thermal Light Souces — •Daniel Bhatti[1,2], Anton Classen[1,2], Steffen Oppel[1], Raimund Schneider[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlan-

gen, Germany

N00N-states have been introduced originally to produce super-resolving interference patterns by use of collective N-photon states propagating along two possible quantum paths [1]. Recent experiments have shown that N independent, incoherently emitting thermal light sources (TLS) can generate similar super-resolving multiphoton interferences when measuring the mth-order intensity correlation function for $m = N$ and if $m-1$ detectors are placed at particular positions [2]. Employing the same $m-1$ fixed detector positions we reveal that N00N-like interferences of arbitrary order can be generated with merely $N = 2$ independent TLS, when measuring higher-order intensity correlation functions with $m \geq 2$ and at least $m-1$ moving detectors. We show that the resulting interference patterns can be interpreted as N00N-like Hanbury Brown and Twiss interferences.

[1] A. N. Boto, et al., Phys. Rev. Lett. 85, 2733 (2000).
[2] S. Oppel, et al., Phys. Rev. Lett. 109, 233603 (2012).

Q 62.72 Thu 16:15 Redoutensaal

Machine Learning to tackle the Entanglement Separability Problem in the Bloch Space — •Klaus Kades[1], Benjamin Classen[1], Matthias Weidemüller[1,2], and Zhen-Sheng Yuan[3] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, 201315 Shanghai, China — [3]Department of Modern Physics, University of Science and Technology of China, 230026 Hefei, China

Determining entanglement and separability is still an open problem for multipartite quantum systems. By transforming the density matrix into the Bloch space, we have a new different access to physical quantities. Lu et al. have shown that entangled and separable states occupy certain regions in this new space (arXiv: 1705.01523). Through analyzing the state space in great depth and by developing a new way to generate random density matrices we can now apply Machine Learning algorithms to identify entangled and separable states.

Q 62.73 Thu 16:15 Redoutensaal

Measurement of Quantum Memory Effects and its Fundamental Limitations — •Matthias Wittemer, Jan-Philipp Schröder, Govinda Clos, Ulrich Warring, Heinz-Peter Breuer, and Tobias Schaetz — Physikalisches Insitut, Albert-Ludwigs-Universität Freiburg

Any realistic quantum system interacts with its environment. Thereby, the open system builds up entanglement and correlations with the environment and exchanges information. Trapped ions offer unique control of internal and external degrees of freedom and are well-suited to engineer closed and open quantum systems. This enables systematic studies of entanglement, decoherence, and thermalization in quantum systems of variable complexity [1]. With our trapped-ion system we measure the flow of information in a closed quantum system and characterize associated memory effects [2]. Thereby, we reveal that the nature of projective measurements in quantum mechanics leads to a nontrivial bias in non-Markovianity measures. We precisely quantify such bias in our trapped-ion system in a regime where numerical simulations are still tractable. Thereby, we challenge current understandings of non-Markovian quantum dynamics by approaching from a most simple showcase [3]. A combination of extended measures for quantum memory effects and our scalable experimental approach can provide a versatile reference, relevant for understanding more complex systems.

[1] G. Clos *et al.*, PRL 117, 170401 (2016), [2] H.-P. Breuer *et al.*, PRL 103, 210401 (2009), [3] M. Wittemer *et al.*, arXiv:1609.04158 (2016)

Q 62.74 Thu 16:15 Redoutensaal

Quantum non-Markovianity with single spins in diamond — •Philipp Vetter[1], Jan Haase[2], Thomas Unden[1], Andrea Smirne[2], Susana Huelga[2], and Fedor Jelezko[1] — [1]Insitute for Quantum Optics, Ulm University, D-89081 Ulm — [2]Institute for Theoretical Physics, Ulm University, D-89081 Ulm

We present an investigation of quantum non-Markovianity with single spins in diamond. We utilize the nitrogen vacancy centre, which enables full control of its electron spin as well as the inherent nitrogen spin. Non-Markovian dynamics are often linked to memory effects inside the environment, which allow a backflow of information into the system of interest [1]. Ramsey experiments on the electron spin are performed to demonstrate precise control of coherence revivals via the population of the nitrogen spin. In addition, we examine the noise floor felt by the electron spin, which originates from further impurities and spins in the diamond lattice. Using Bayesian inference, we estimate the deviation from a true semigroup evolution by polarizing the nitrogen into the non-interacting hyperfine state and a subsequent measurement of the free induction decay.

[1] Rivas, A., Huelga, S. F., & Plenio, M. B. (2014). Quantum non-Markovianity: characterization, quantification and detection. Reports on Progress in Physics, 77(9), 094001.

Q 62.75 Thu 16:15 Redoutensaal

Rotational Decoherence of Molecular Superrotors — •Benjamin A. Stickler[1], Farhad Taher Ghahramani[2], and Klaus Hornberger[1] — [1]Faculty of Physics, University of Duisburg-Essen, Duisburg, Germany — [2]School of Physics, Institute for Research in Fundamental Sciences, Tehran, Iran

A molecule revolving in a thermal gas experiences random collisions with the surrounding gas atoms. We show how these collisions serve to decohere an initial superposition of angular momentum eigenstates if the molecule rotates multiple times during the scattering process. The corresponding Markovian master equation, derived from the quantum linear Boltzmann equation [1], relates the decoherence rate to the microscopic scattering amplitudes of a single collision. We calculate the decoherence rate for nitrogen molecular superrotors and compare it to recent experiments [2].

[1] B. Vacchini, and K. Hornberger, Phys. Rep. 478, 71 (2009) [2] A. A. Milner, A. Korobenko, J. W. Hepburn, and V. Milner, Phys. Rev. Lett. 113, 043005 (2014)

Q 62.76 Thu 16:15 Redoutensaal

Describing a quantum eraser experiment with a symbolic in-out formalism — •Nico Klein[1,2,3], Manuel Daiber[1,2], Lutz Kasper[2], and Matthias Freyberger[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm — [2]Physics Department, University of Education D-73525 Schwäbisch Gmünd — [3]qutools GmbH D-81379 München

Teaching the essential principles of quantum physics to undergraduate students or the general public still remains a challenging task. Here, it is shown how fascinating real-time experiments such as a quantum eraser can contribute to a more phenomenon based and deeper understanding of critical concepts like coherence. An easy to adjust source of single photons and a Michelson interferometer are combined in a modular tabletop setup to perform the experiment. Furthermore, an in-out formalism developed using basic experimental results can be deployed to explain and interpret even these complex quantum optical setups while retaining professional accuracy. Results originate from a cooperation of Ulm University, University of Education Schwäbisch Gmünd and qutools GmbH München.

Q 62.77 Thu 16:15 Redoutensaal

Collective light-matter interaction in the presence of spin-orbit coupling of light — •Zaneta Kurpias, Stefan Walser, Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien

In strongly confined light fields, spin-orbit coupling of light leads to an inherent link between the light's local polarization and its propagation direction. This can lead to chirality, i.e. direction dependent interaction between light and matter [1]. In a previous experiment we showed that spin-orbit coupling of light leads to systematic wavelength-scale position errors when imaging subwavelength-scale particles in a microscopy setup. To measure this effect we image a single gold nanoparticle with an optical microscope. Using centroid-fitting techniques, we observed a shift between the emitter's measured and actual position. This difference depends on the polarization of the light emitted by the particle and is comparable to the optical wavelength.

In the next step, we plan to expand our current setup to study light-matter interactions of many particles in the presence of chiral effects. This allows us to explore the influence of spin-orbit coupling on collective effect such as sub- and superradiance.

[1] Nature 541, 473-480, (2017)

Q 62.78 Thu 16:15 Redoutensaal

Coupling cold atoms to a cryogenically cooled optomechanical device — •Philipp Christoph[1], Tobias Wagner[1], Felix Klein[1], Hai Zhong[2], Alexander Schwarz[2], Roland Wiesendanger[2], Klaus Sengstock[1], and Christoph Becker[1] — [1]ZOQ-Center for Optical Quantum Technologies, Luruper Chaussee 149, 22761

Hamburg — [2]Institute of Applied Physics, University of Hamburg, Jungiusstraße 9-11, 20355 Hamburg

Quantum hybrid systems have recently attracted considerable interest due to their prospects of realizing new setups that combine the benefits of several very different quantum systems. We have built an apparatus to optically couple ultracold atoms to a cryogenically cooled membrane oscillator and present work towards preparing both quantum systems in their ground state while they are coupled to each other. Here we characterize and quantify the atom-oscillator coupling, through sympathetic cooling of the membrane by laser cooled cold atoms inside a magneto optical trap. We investigate the sympathetic cooling rate as a function of different experimental parameters of the magneto optical trap and the coupling beam. We compare our data to a simple theoretical model using two coupled harmonic oscillators [1] and find good agreement in certain parameter regimes. For large optical densities of the atomic cloud a more refined model [2] is required to explain the observed heating of the membrane. This work is supported by the DFG via grants of Wi1277/29-1, BE 4793/2-1 and SE 717/9-1.

[1] B. Vogell et al, Phys. Rev. A 87, 023816 (2013)
[2] J. K. Asboth et al, Phys. Rev. A 77, 063424 (2008)

Q 62.79 Thu 16:15 Redoutensaal

Capillary Electrophoresis of Single Proteins via Interferometric Scattering Microscopy — •Mahyar Dahmardeh[1,2], Matthew P. McDonald[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, D-91058 Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nuremberg, D-91058 Erlangen, Germany

Electrophoresis has been used as the gold standard assay for studying protein structures and proteomics. However, generally there are certain limitations inherent in the design such as the requirement for a large sample size, long experimental integration times and tedious post processing procedures. All of these make conventional electrophoresis techniques arduous and in some cases impossible to implement. Over the course of the last few years we have developed a label-free optical technique that senses individual nanoparticles and proteins using the interferometric detection of scattered light (iSCAT). iSCAT signals arise from interference between scattered waves and the light backreflected from the microscope cover-glass surface. Since iSCAT operates by way of single protein optical detection, combining it with electrophoresis overcomes the afore mentioned constraints. We have thus developed an electrophoresis based technique compatible with iSCAT-based detection. Initial measurements indicated that this approach is viable and single proteins have been synchronously detected in a prototype iSCAT based apparatus. This work will seek to establish a novel method as a robust, easy-to-use procedure that can markedly supplement existing electrophoretic techniques.

Q 62.80 Thu 16:15 Redoutensaal

Physics and Medicine — •Vahid Sandoghdar — Max-Planck-Institut für die Physik des Lichts, Erlangen

Physicists have a long tradition in developing methods and concepts for the advance of life sciences. In recent decades, however, “medical physics” has been mostly associated with medical “technology” such as methods in radiology, where issues in patient diagnostics and clinical care are addressed. With the recent progress in biophysics and nano-optics, a new era is being born where physicists employ their experimental and theoretical toolboxes to *fundamental* questions in medical research and cell biology. In this poster presentation, I shall discuss some of the current trends in this exciting research area as well as our group’s activities within the framework of the newly founded Zentrum für Physik und Medizin in Erlangen.

Q 62.81 Thu 16:15 Redoutensaal

Continuously frequency-tunable diode laser phase locked to an optical frequency comb — •Maximilian Ammenwerth, Lukas Ahlheit, Wolfgang Alt, Deepak Pandey, and Dieter Meschede — Institut für Angewandte Physik, Wegelerstr. 8, D-53115 Bonn

We demonstrate a locking scheme of a diode laser to the spectrum of an optical frequency comb that allows for continuous frequency tuning of the phase locked laser. The heterodyne beat of a comb line and the laser operating at 770 nm is compared to a reference signal from a direct digital synthesizer using a phase-frequency discriminator. The output of this phase-sensitive comparison serves as error signal that is used for applying feedback to laser current and piezo. We compare different scanning schemes that make use of an acousto-optical modulator to scan continuously over comb lines [1,2]. In order to tune the laser frequency over multiple comb lines, fast jumps of the lock point are required. These jumps are analyzed in detail and the phase stability during this process is quantified. We show an application as a complete optical frequency synthesizer based on a microcontroller that allows for setting the optical frequency via an analog voltage or a command line interface.

[1] Will Gunton, Mariusz Semczuk, and Kirk W. Madison. Method for independent and continuous tuning of n lasers phase-locked to the same frequency comb. Optics Letters, 40(18):4372, sep 2015.
[2] John D. Jost, John L. Hall, and Jun Ye. Continuously tunable, precise, single frequency optical signal generator. Opt. Express, 10(12):515-520, Jun 2002.

Q 62.82 Thu 16:15 Redoutensaal

SHG in periodically poled crystals for cooling of relativistic ion beams — •Janika Schwalbach, Daniel Kiefer, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstr. 7, 64289, Darmstadt

Fast tunable cw laser systems have many applications. Among others such as laser spectroscopy, cooling of relativistic ion beams is an application of interest [1]. The method is usually employed in addition to electron- and stochastic cooling and uses a laser beam instead to reduce the phase space density of an ion beam circulating in a storage ring. Such a fast tunable cw laser system has been developed and tested successfully cooling C^{3+}-ions [2]. Since then the 257-nm-laser system was further improved. Focus was the LBO based SHG build-up cavity. It is replaced by a single periodically poled crystal based on MgO:PPLN or MgO:PPSLT. Latest results and further aspects will be presented.

[1] U. Schramm, D. Habs. Crystalline ion beams. Progress in Particle and Nuclear Physics 53 (2004), 583-677. [2] T. Beck. Lasersystem zur Kühlung relativistischer C^{3+}-Ionenstrahlen in Speicherringen. Dissertation. Technische Universität Darmstadt (2015).

Q 62.83 Thu 16:15 Redoutensaal

High Power SHG Laser System for 671nm — •Manuel Jäger, Daniel Hoffmann, Thomas Paintner, Wladimir Schoch, Wolfgang Limmer, and Johannes Hecker Denschlag — Institut für Quantenmaterie, Universität Ulm, Deutschland

High-power, stable, single mode lasers have developed into important prerequisites for cold atom production and manipulation. We have built up a narrow-linewidth (< 2 MHz) all-solid-state laser source at 671nm which can be stabilized to the D_2 line of ^{6}Li and provides an output power of 1.1 watt. The construction is based on a design of the group of Christophe Salomon [1,2]. The laser system is based on a ring laser at a wavelength of 1342nm which is frequency-doubled in a cavity.

The ring laser consists of a diode-pumped Nd:YVO_4 crystal inside a bow-tie cavity. By using frequency-selective elements we can stabilize the laser for single mode emission and reach an output power of 3-4 watt.

We frequency-double this light using a ppMgO:LN crystal, which features a high conversion efficiency. To increase the second harmonic generation this crystal is placed in an enhancement cavity in bow-tie configuration.

[1] Norman Kretzschmar, Ulrich Eismann, Franz Sievers, Frédéric Chevy and Christophe Salomon, *Opt. Express 25*, 14840-14855 (2017)
[2] U. Eismann, F. Gerbier, C. Canalias, A. Zukauskas, G. Tré, J. Vigué, F. Chevy, C. Salomon, *Appl. Phys. B* 106, 25 (2012).

Q 62.84 Thu 16:15 Redoutensaal

Investigations on a compact low cost molecular iodine laser — Bernd Wellegehausen[1], •Walter Luhs[2], and Mukul Goyal[3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Photonic Engineering Office, Freiburger Str. 33, 79427 Eschbach, Germany — [3]ALKAAD, D-25 Panchsheel Enclave, New Delhi 110017, India

Cw oscillation of molecular iodine on many lines in the range of 557 - 802 nm pumped with a low power common diode pumped and frequency doubled solid state laser (DPSSL) is reported. The DPSSL is temperature stabilized, operates in single frequency and can be tuned by about 2 nm at 532 nm. Operation conditions of this simple and low-cost iodine ring laser will be described and possible applications will be discussed. Parts of this contributions have been published already (Luhs, W., Wellegehausen, B. & Goyal, M. Appl. Phys. B (2017) 123:

125).

Q 62.85 Thu 16:15 Redoutensaal

Phase lock between diode lasers — Stefan Baumgärtner, Manfred Hager, Christoph Raab, Stephan Ritter, and •Stephan Falke — TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Gräfelfing/München, Germany

Light emitted by cw lasers represents an oscillator with a high quality factor, which is the ratio of the frequency of the light and the linewidth of the laser. For free-running external cavity diode lasers (ECDL) it is typically about one million. By ensuring, in addition, that the absolute frequency of the laser is fixed, one is able to efficiently drive optical transitions of atoms, molecules and ions, e.g. for laser cooling, which relies on the high quality factor of the oscillator.

To stabilize the frequency difference between two lasers, phase locks are commonly applied. This allows for difference frequencies of several GHz and for a synchronization of the two oscillators, which is essential e.g. for addressing narrow two-photon resonances. Other application examples include lasers addressing atoms in high magnetic fields or the stabilization of cw lasers using a frequency comb.

Phase locking two laser fields to each other is possible by utilizing their beat signal, typically recorded with a fast photo-detector, and a fast feedback to one of the lasers. We realized a phase lock between two ECDLs and demonstrate 99% of phase locked light between two ECDL with free running linewidth of 100 kHz. We discuss the requirements on servo and laser, leading to a roll-over of the feedback at more than 1 MHz with commercially available components.

Q 62.86 Thu 16:15 Redoutensaal

Quantitative analysis of a chemical reaction in a microfluidic device using stimulated Raman scattering microscopy — •Peter Fimpel, Martin Josef Winterhalter, and Andreas Zumbusch — Universität Konstanz

Microfluidic devices offer the possibility to monitor reactions with precise control of the reactants ratios. The laminar flow in our device allows us to visualize the reaction kinetics due to pure diffusive mixing. SRS is a perfect tool to quantitatively monitor such processes since it has chemical contrast, is free of non-resonant background and scales linearly with the chemical concentration. This enables us to measure the local concentration with submicrometer spatial resolution and fast acquisition times compared to spontaneous Raman scattering microscopy.

Q 62.87 Thu 16:15 Redoutensaal

Two-color coherent control at a nanotip: from above-threshold photoemission to spectroscopy on a metallic surface — •Ang Li[1], Timo Paschen[1], Michael Förster[1], Michael Krüger[1], Florian Libisch[2], Chritoph Lemell[2], Georg Wachter[2], Thomas Madlener[2], Joachim Burgdörfer[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstr. 1, 91058 Erlangen — [2]Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstr. 8-10/E136, 1040 Wien

Nanotips are routinely used as electron sources in high-resolution electron microscopes [1] and as a basis for studying strong-field phenomena at the surface of solids [2]. When these tips are excited with a fundamental femtosecond laser field and its second harmonic one can coherently control the electronic dynamics on the (sub-) femtosecond time scale. Here, we report on such laser-triggered electron emission studied as a function of pulse delay, optical near-field intensities, dc bias field and final photoelectron energy. Further, a spectroscopy of this coherent signal is presented based on a variation of the wavelength of the two laser fields, revealing a new method of studying the electronic properties of surfaces of different materials. The experimental results are discussed in the framework of quantum-pathway interference supported by local density of states simulations.

[1] A. V. Crewe et al., Rev. Sci. Instrum. 39, 576 (1968).
[2] R. Bormann et al., Phys. Rev. Lett. 105, 147601 (2010).

Q 62.88 Thu 16:15 Redoutensaal

Optical Krypton spectroscopy in magnetic fields — •Peter Zwissler — Universität Tübingen, Germany

We are trying to set up a saturation spectroscopy using a Krypton gas cell. A DC-discharge will excite the atoms in a meta stable state and the spectroscopy laser will drive a transition between this state and another higher excited state. According to theoretical calculations, this set up is highly sensitive to magnetic fields, which can be exploited to build a magnetometer. The poster will give a report about the theory and the current status of the project.

Q 62.89 Thu 16:15 Redoutensaal

Towards high spatial resolution temperature sensing in an optical fiber amplifier — •Alexandra Popp[1,2], Florian Sedlmeir[1,2], Atiyeh Zarifi[3], Birgit Stiller[3], Christian R. Müller[1,2], Ulrich Vogl[1,2], Victor Bock[4], Thomas Schreiber[4], Benjamin J. Eggleton[3], Andreas Tünnermann[4], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Germany. — [3]School of Physics, University of Sydney, Australia. — [4]Fraunhofer Institute for Applied Optics and Precision Engineering IOF , Jena, Germany.

Extremely powerful lasers are required for various applications in science and industry. The output power of fiber lasers, however, has limits. When the light power inside a single-mode fiber amplifier reaches a certain threshold, the intensity profile out of the fiber starts to become distorted due to so called thermal mode instabilities (TMI) which are not yet fully understood and experimentally difficult to characterize. To investigate TMI, fast in-fiber temperature sensing with a high resolution is required. This has not been achieved yet. We present first measurements towards a setup for high precision in-fiber temperature measurements of an optical fiber amplifier based on Brillouin sensing.

Q 62.90 Thu 16:15 Redoutensaal

Optical modules for dual-species atom interferometry on sounding rockets — •Moritz Mihm[1], Jean Pierre Marburger[1], André Wenzlawski[1], Ortwin Hellmig[6], Klaus Doeringshoff[2], Markus Krutzik[2], Achim Peters[2], Patrick Windpassinger[1], and the MAIUS Team[1,2,3,4,5] — [1]Institut für Physik, JGU Mainz — [2]Institut für Physik, HU Berlin — [3]IQO, LU Hannover — [4]FBH, Berlin — [5]ZARM, Bremen — [6]ILP, UHH Hamburg

More and more quantum technologies are used in extreme environments. The operation outside the laboratory makes high demands on the experiment and especially the laser system regarding miniaturization, power consumption, mechanical and thermal stability. In our systems, optical modules consisting of Zerodur based optical benches with free-space optics are combined with fiber components. Suitability of the technology has been demonstrated in the successful sounding rocket missions FOKUS, KALEXUS and MAIUS.

Here, we report on the optical modules for a quantum gas experiment performing dual-species atom interferometry with BECs on sounding rockets. The modules are used on the one hand to stabilize the laser frequencies and on the other hand to distribute, overlap and switch the laser beams. This includes the overlap and joint fiber coupling of beams at 767 nm and 780 nm in the same polarization state to cool and manipulate atoms of both species simultaneously.

Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50 WP 1433 and 50 WP 1703.

Q 62.91 Thu 16:15 Redoutensaal

Brillouin and Raman Measurements of Water for Temperature and Salinity Prediction — •Erik Fitzke, Andreas Zipf, David Rupp, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

We are working on a LIDAR system for airborne measurements of ocean temperature and salinity. Our goal is to provide oceanographers, marine biologists and meteorologists with a cost-efficient and flexible measurement system capable of depth-resolved acquisition of both parameters in the mixing layer of water down to 100 m depth. We present our recent progress in methods based on Brillouin and Raman scattering.

We continued out preceding work using the Brillouin approach which relies on the analysis of the Brillouin peak shift and peak width for simultaneous measurement of both temperature and salinity. New results for empirical relationships between the variables of interest and the Brillouin peak width will be presented.

As a complementary approach we analyzed the Raman scattering spectrum. By using Partial Least Squares Regression and Artificial Neural Networks we were able to determine temperature and salinity from the spectrum. We will present an overview of the methodology and results for the prediction accuracy of both parameters for the simultaneous analysis of the Raman spectrum.

Q 62.92 Thu 16:15 Redoutensaal

An XUV and soft X-ray split-and-delay unit for FLASH II — •Dennis Eckermann[1], Sebastian Roling[1], Matthias Rollnik[1], Marion Kuhlmann[2], Elke Plönjes[2], Frank Wahlert[1], and Helmut Zachairas[1] — [1]Physikalisches Institut, Universität Münster, Wilhelm-Klemm Straße 10, 48149 Münster, Germany — [2]Deutsches Elektronen Synchrotron, Notkestraße 85, 22607 Hamburg, Germany

An XUV and soft X-ray split-and-delay unit is built that enables time-resolved experiments covering the whole spectral range of FLASH II from $h\nu = 30$ eV up to 2500 eV. With wave front beam splitting and grazing incidence angles a maximum delay of -6 ps $< \Delta t < +18$ ps will be possible with a sub-fs resolution. Two different coatings are required to cover the complete spectral range. Therefore, a design that is based on the three dimensional beam path of the SDU at BL2 at FLASH has been developed which allows choosing the propagation via two sets of mirrors with these coatings. A Ni-coating will allow a total transmission on the order of T = 55% for photon energies between 30 eV and 600 eV at a grazing angle $\theta = 1.8°$ in the variable delay line. In the fixed delay line the grazing angle is set so $\theta = 1.3°$. With a Pt-coating a transmission of T > 13 % will be possible for photon energies up to 1500 eV. For a future upgrade of FLASH II the grazing angle can be changed to $\theta = 1.3°$ in order to cover a range up to $h\nu = 2500$ eV.

Q 62.93 Thu 16:15 Redoutensaal

A split-and-delay unit for the European XFEL: Enabling hard x-ray pump/probe experiments at the HED instrument — •Sebastian Roling[1], Karen Appel[2], Peter Gawlitza[3], Harald Sinn[2], Frank Wahlert[1], Ulf Zastrau[2], and Helmut Zachairas[1] — [1]Physikalisches Institut, Univerität Münster, Wilhelm-Klemm Straße 10, 48149 Münster — [2]European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany — [3]Fraunhofer Institut IWS, Winterbergstraße 28, 01277 Dresden, Germany

For the High Energy Density (HED) instrument at the SASE2 - Undulator at the European XFEL an x-ray split-and-delay unit (SDU) is built covering photon energies from hν = 5 keV up to hν = 24 keV. This SDU will enable time-resolved x-ray pump / x-ray probe experiments as well as sequential diffractive imaging on a femtosecond to picosecond time scale. Further, direct measurements of the temporal coherence properties will be possible by making use of a linear autocorrelation. The x-ray FEL pulses are split by a sharp edge of a silicon mirror (BS) coated with Mo/B_4C and W/B_4C multilayers. Both partial beams then pass variable delay lines. For different wavelengths the angle of incidence onto the multilayer mirrors will be adjusted in order to match the Bragg condition. Because of the different incidence angles, the path lengths of the beams will differ as a function of wavelength. Hence, maximum delays between ±1.0 ps at hν = 24 keV and up to ±23 ps at hν = 5 keV are possible.

Q 62.94 Thu 16:15 Redoutensaal

Wavefront propagation study concerning the influence of non-ideal mirror surfaces inside a split-and- delay unit on the focusability of XFEL-pulses — •Victor Kaercher[1], Sebastian Roling[1], Liobov Samoylova[2], Karen Appel[2], Harald Sinn[2], Frank Siewert[3], Ulf Zastrau[2], and Helmut Zacharias[1] — [1]Physikalisches Institut, WWU Münster, Wilhelm-Klemm Straße 10, 48149 Münster, Germany — [2]European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany — [3]Helmholtz-Zentrum für Materialien und Energie, Albert-Einstein- Straße 15, 12489 Berlin, Germany

For the High Energy Density (HED) instrument at the SASE2 - Undulator at European XFEL an x-ray split-and- delay unit (SDU) is built covering photon energies from $h\nu = 5$ keV up to $h\nu = 24$ keV. This SDU will enable time-resolved x-ray pump / x-ray probe experiments as well as sequential diffractive imaging on a femtosecond to picosecond time scale. In order to reach intensities on the order of $10^{15}\ W/cm^2$ the XFEL pulses will be focused by means of compound refractive lenses (CRL) to a diameter of $D = 24\mu m$. The influence of wavefront disturbances caused by height- und slope-errors of the mirrors inside the SDU on the quality of the two focused partial beams is studied by wavefront propagation simulations using the WPG-framework.

Q 62.95 Thu 16:15 Redoutensaal

A rapidly tunable (520 − 680 nm) narrow-bandwidth ps-laser pulse source based on a 1030 nm 80 MHz oscillator — •Lukas Ebner, Martin Josef Winterhalder, and Andreas Zumbusch — Universität Konstanz

In optical spectroscopy the bandwidth of the light directly defines the spectroscopic resolution. We present a method to generate narrow bandwidth ps-laser pulses with a rectangular shape featuring sharp edges in the time domain. To this end we use the soliton fission of a 250 fs laser pulse at 1030 nm in a photonic crystal fiber (PCF) to generate a soliton at around 1300 nm. By frequency doubling this soliton in a periodically poled lithium niobate (PPLN) crystal, we obtain the narrow bandwidth rectangular ps-pulses between (520 − 680 nm). Tunability is given by employing a fan out PPLN with different poling periods.

Q 62.96 Thu 16:15 Redoutensaal

Accurate ultra-broadband amplitude andphase shaping in the visible — •Philipp Hillmann, Alexander Kastner, Jens Köhler, Cristian Sarpe, Hendrike Braun, Arne Senftleben, and Thomas Baumert — Universität Kassel, Institut für Physik und CINSaT, Heinrich-Plett-Str. 40, D-34132 Kassel, Germany

Femtosecond laser pulse shaping is the key technology in quantum control. So far, we were able to demonstrate pulse shaping with sub-cycle temporal accuracy making use of phase and amplitude modulation of femtosecond laser pulses in the infrared spectral region [1]. The experimental demonstration of molecular strong-field control schemes was achieved [2].

Supercontinua exceeding one octave are a prerequisite to generate few-cycle light pulses in the temporal domain. Combining supercontinuum generation spanning from the ultraviolet to near-infrared spectral region with high-throughput prism based pulse shaping [3] opens up the possibility to expand the coherent control techniques to a broader range of electronic systems.

We present the current status of our setup for ultra-broadband amplitude and phase shaping of femtosecond laser pulses characterized by transient grating frequency resolved optical gating.

[1] J. Köhler *et al.*, Optics Express **19** (12), 11638-11653 (2011)
[2] T. Bayer *et al.*, Physical Review Letters **110**, 123003 (2013)
[3] T. Binhammer *et al.*, IEEE **41** (12), 1552-1557 (2006)

Q 62.97 Thu 16:15 Redoutensaal

Towards sub-two-cycle optical pulse compression from Ti:sapphire oscillators — •Philip Dienstbier[1], Takuya Higuchi[1], Francesco Tani[2], Michael Frosz[2], John Travers[3], Philip St. J. Russell[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstraße 1, 91058 Erlangen — [2]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [3]Heriot-Watt University, Edinburgh, EH14 4AS, United Kingdom

Strong-field effects within gases and solids require pulse energies in the μJ to mJ regime achievable with amplified lasers at low repetition rates of a few to hundreds of kHz. For systems such as metal nano-emitters [1] or 2D materials [2] the pulse energies necessary to enter the strong-field regime can be lowered to below 1 nJ due to field enhancement or the special band structure. In this pulse energy range Ti:sapphire oscillators can be used providing pulses as short as two optical cycles with typical repetition rates of 80 MHz. An upgrade of the laser source by further shortening the pulse duration should be beneficial for the study of strong-field effects as the contrast between peaks in the electric-field waveform is enhanced. For this we present a setup to spectrally broaden the output of a Ti:sapphire oscillator by a customized solid-core photonic crystal fiber and a prism-based 4f-pulse compressor with expected compression close to a single optical cycle.

[1] M. Krüger, M. Schenk, M. and P. Hommelhoff, Nature **475**, 78.
[2] T. Higuchi, C. Heide, K. Ullmann, H. B. Weber and P. Hommelhoff, Nature **550**, 224-228.

Q 62.98 Thu 16:15 Redoutensaal

Compression of femtosecond laser pulses using self-phase modulation in dielectric media — •Torben Purz, Sergey Zayko, Ofer Kfir, and Claus Ropers — University of Göttingen, 4th Physical Institute, Göttingen, Germany

The generation of ultrashort laser pulses stimulated the investigation of ultrafast processes at the pico-, femto- and attosecond time scale in physics, chemistry and energy research [1-3]. Pulse compression relies on nonlinear effects, and intense femtosecond pulses are often compressed using a long gas-filled hollow-core waveguide, requiring tight focusing, high beam stability and additional beampath of few meters.

In this work, the compression of femtosecond laser pulses is achieved in solid plates, resulting in a simple, compact and stable setup [4]. We employ self-phase modulation in fused silica and N-BK7 glass to compress 1-2 mJ pulses from a Ti:Sapphire amplifier of 43 fs pulse duration, down to 20 fs. Numerical simulations indicate that self-phase-modulation, self-steepening and intrapulse Raman scattering determine the final pulse shape, in good agreement with the experimental data. We investigate the coupled group-delay dispersion and third-order dispersion dependence of the spectral broadening. The compressed pulses are applied for second harmonic and high-harmonic generation, showing a substantial increase of the harmonics flux.

[1] Zewail *et al.*, Science **266**, 1359-1364 (1994)
[2] Gattass *et al.*, Nature Photonics **2**, 219-225 (2008)
[3] Ditmire *et al.*, Nature **398**, 489-492 (1999)
[4] Kung *et al.*, Optica **6**, 400-406 (2014)

Q 62.99 Thu 16:15 Redoutensaal

Novel laser-driven photonic structures for high efficiency electron acceleration — •Peyman Yousefi, Joshua McNeur, Martin Kozák, Norbert Schönenberger, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstr. 1, 91058 Erlangen

Dielectric laser acceleration (DLA) has proven to be a reliable concept for future table-top particle accelerators. In DLA, electrons traverse the accelerating near fields excited by ultrafast lasers impinging on dielectric nanostructures. Acceleration of electrons with varying energies has been demonstrated with gradients approaching 1 GeV/m [1]. To realize longer interaction length over multiple stages, structures that efficiently convert the incoming laser field into the accelerating mode are critical. A dual pillar grating, described here, has proven to be a good candidate for high efficiency acceleration. Further, it provides a proper symmetry in the field profile and reduces the deflecting forces. Here we present electron acceleration with a dual pillar silicon grating using a distributed Bragg reflector (DBR). We address the effect of DBR on the acceleration gradient and also report on a new geometry of dual pillars for higher acceleration gradients.

1.England, R. J.et al. Dielectric laser accelerators. Rev.Mod. Phys. 86, 1337 (2014).

Q 62.100 Thu 16:15 Redoutensaal

Numerical studies of electron pulse broadening in laser-triggered sources — •Johannes Illmer, Joshua McNeur, Martin Kozák, Norbert Schönenberger, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

In the field of ultrafast physics, femtosecond electron pulses have proven to be a useful tool to study ultrafast phenomena in condensed matter systems [1]. One way of generating these short electron pulses is the laser-triggering of an electron source, designed for DC beams, with femtosecond UV laser pulses. Due to effects such as space charge, trajectory differences and dispersion in vacuum, the initial temporal profile of the electron pulses becomes broadened, limiting the achievable resolution. We present numerical studies of this effect in order to investigate the pulse broadening behavior of laser-triggered electron sources. The electrostatic fields of the electron gun are calculated with a Poissonian field solver. Trajectory and space charge effects are calculated via a 5th order Runge-Kutta algorithm. A first validation of this method was shown by correlating experimental results with a numerical study of the electron pulse broadening. Furthermore, we discuss investigations of new source configurations to identify setups that minimize such broadening. A special focus is the development of new source types for application in dielectric laser accelerators (DLA)[2].

[1] A. H. Zewail and J. M. Thomas, "4D Electron Microscopy: Imaging in Space and Time", Imperial College Press (2010)
[2] R. Joel England et al., Rev. Mod. Phys. 86, 1337 (2014)

Q 62.101 Thu 16:15 Redoutensaal

Spatiotemporal characterization of laser filaments in noble gases — •Christoph Jusko[1], Lana Neoricic[2], Shiyang Zhong[2], Miguel Miranda[2], Cord Arnold[2], and Milutin Kovacev[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Deutschland — [2]Division of Atomic Physics, Lund University, Professorsgatan 1, 223 63 Lund, Schweden

Laser filaments in noble gases show highly nonlinear temporal and spatial dynamics along the propagation direction, e.g. leading to high peak intensities, spectral broadening and interesting effects like self-shortening of femtosecond laser pulses. We present an experimental approach for a comprehensive, propagation-position-dependent study of the temporal as well as the spatial filament dynamics taking place in argon. Later, insights about the dynamics could support pump-probe studies on noble gas filaments in order to detect Kramers-Henneberger atoms.

Q 63: Cold atoms VII - micromachines (joint session A/Q)

Time: Friday 10:30–11:50 Location: K 0.011

Group Report Q 63.1 Fri 10:30 K 0.011

Thermodynamics of single-ion machines — •Ulrich Poschinger[1], David von Lindenfels[1], Oliver Gräb[1], Martin Wagener[1], Vidyut Kaushal[1], Jonas Schulz[1], Alexander Friedenberger[2], Eric Lutz[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

The thermodynamic behaviour of small machines, ultimately far from the thermodynamic limit, is currently attracting much interest. We present the realization of a single-ion 'heat engine' [1]. The working medium is the spin degree of freedom of a single $^{40}Ca^{+}$ ion, positioned in an optical standing optical wave[2], which couples the spin to the ion motion. The ion is subjected to alternating optical pumping pulses. This gives rise to an effective resonant force mediated by the standing wave, which leads to the onset of oscillations of the ion position, ranging from the motional ground state to some tens of motional quanta. We analyze the work fluctuations occuring while the thermal energy from the laser reservoirs is transferred to the ion motion, and quantify the extractable work.

We also present ongoing work on the experimental study of the performance of an autonomous single-ion 'wall-clock', which is, according to recent theoretical work[3], tied to its waste heat production.

[1] Rossnagel et al., Science **352**, 325 (2016)
[2] Schmiegelow et al., PRL **116**, 033002 (2016)
[3] Erker et al., PRX **7**, 031022 (2017)

Q 63.2 Fri 10:50 K 0.011

Unifying paradigms of quantum refrigeration: how resource-control determines fundamental limits — •Fabien Clivaz[1], Ralph Silva[1], Géraldine Haack[1], Jonatan Bohr Brask[1], Nicolas Brunner[1], and Marcus Huber[2] — [1]Department of Applied Physics, University of Geneva, 1211 Geneva 4, Switzerland — [2]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria

In classical thermodynamics the work cost of control can typically be neglected. On the contrary, in quantum thermodynamics the cost of control constitutes a fundamental contribution to the total work cost. Evaluating this contribution is an important but non-trivial problem. Here, focusing on quantum refrigeration, we show how the level of control determines the fundamental limits to cooling. We compare coherent versus incoherent operations, and derive the minimal achievable temperature and associated work cost. We discuss both the single-shot and asymptotic regimes. Our work provides a unified picture of the different approaches to quantum refrigeration developed in the literature, including algorithmic cooling, autonomous quantum refrigerators, and the resource theory of quantum thermodynamics.

Q 63.3 Fri 11:05 K 0.011

Is a Stern-Gerlach splitter possible with an ion beam? — •Carsten Henkel[1], Georg Jacob[2], Felix Stopp[2], Ferdinand Schmidt-Kaler[2], Yonathan Japha[3], Mark Keil[3], and Ron Folman[3] — [1]Universität Potsdam — [2]J. Gutenberg-Universität Mainz — [3]B Gurion University of the Negev, Beer Sheva

The Stern-Gerlach effect for free electrons has been discussed since the advent of quantum mechanics and was found to be challenging due to the uncertainty in the Lorentz force [1,2]. We propose realising a spin filter for a pulsed ion beam using the Stern-Gerlach force of a magnetic micro-grating. The field gradient is created by an array of wires integrated into a microchip. In distinction to the standard setup, both the spin and the magnetic field rotate along the beam path [3]. The Ca^+ ions are laser cooled and released from a Paul trap, giving a pulsed beam of approximately 1eV with high brightness and very narrow velocity distribution [4]. Due to the large ion/electron mass ratio, the Lorentz force does not prevent the spin splitting. It can even be put to use, in conjunction with a bias field, in order to balance the image charge interaction and to prevent the ions from crashing onto the chip surface. We discuss semiclassical techniques to simulate the ion trajectories and estimate the spin-dependent splitting of the beam.

[1] B. M. Garraway and S. Stenholm, Contemp. Phys. 43 (2002) 147
[2] H. Batelaan, Am. J. Phys. 70 (2002) 325
[3] E. Enga and M. Bloom, Can. J. Phys. 48 (1970) 2466
[4] G. Jacob & al, Phys. Rev. Lett. 117 (2016) 043001

Q 63.4 Fri 11:20 K 0.011

Neural Network States: an alternative description of quantum many body states. — •Jose Nahuel Freitas and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

As is well known, an exponentially large amount of information is needed to describe general quantum states of quantum many body systems. Thus, in order to simulate quantum systems in classical computers, it is important to identify efficient descriptions of physically relevant states. Typical examples of such efficient descriptions are Matrix Product States (MPS), Projected Entangled Pairs States (PEPS) or, in general, Tensor Network States. These parametrizations of quantum states have been employed with high success to study both the ground state and dynamical properties of quantum lattice models in one and two dimensions. However, the amount and range of the quantum correlations (entanglement) that they can capture is severely limited. Recently, it was proposed to leverage the representational power of Neural Networks in order to describe many body quantum states[Science, 355(6325), 602-606]. The family thus obtained, called Neural Network States, seems to be a promising alternative to study systems that are not tractable with usual methods based on TNS. In this talk, we will describe and review the main properties of these states, possible generalizations, and discuss new techniques to manipulate them.

Q 63.5 Fri 11:35 K 0.011

Probing quantum dynamical pair correlation functions — •Salvatore Castrignano and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The space-time correlations among particles in e.g. condensed matter systems can be experimentally studied via the so-called Time Domain Interferometry proposed in [1]. In particular the dynamical couple correlation function [2] can be obtained from the recorded interferogram. This scheme has sofar been theoretically studied and successfully tested for target systems whose dynamics can be safely described by classical mechanics.

With the growth of interest toward higly correlated quantum materials, the development of experimental techniques for measuring quantum dynamical correlations is getting more and more interest. In this project we then ask if extensions of the above interferometric setup are capable of accessing the quantum dynamical couple-correlation function of a quantum target. The classical and quantum correlations have different properties and through a theoretical analysis of the setup in a full quantum framework it is shown that these differences are experimentally accessible. Moreover, using elements of measurement theory in classical and quantum frameworks [3], we give a heuristic criterion to understand when to expect quantum or classical behaviour of generic correlation functions.

[1] A. Q. R. Baron et al., Phys. Rev. Lett. 79, 2823 (1997)
[2] L. Van Hove, Phys. Rev. 95, 249 (1954)
[3] P. Uhrich et al., Phys. Rev. A 96, 022127 (2017)

Q 64: Quantum Optics and Photonics IV

Time: Friday 10:30–12:30 Location: K 0.016

Q 64.1 Fri 10:30 K 0.016

Quantum noise enhanced through nonlinear effects: extreme events and extreme bunching — •Kirill Spasibko[1,2], Mathieu Manceau[1], Gerd Leuchs[1,2], Radim Filip[3], and Maria Chekhova[1,2,4] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]University of Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Department of Optics, Palacky University, 77146 Olomouc, Czech Republic — [4]Department of Physics, M. V. Lomonosov Moscow State University, 119991 Moscow, Russia

Extreme events and rogue waves are observed for different physical systems. They are especially fascinating because they can lead to catastrophic changes in the system despite being quite rare. However, their probability is still much higher than one expects from Gaussian random processes, i.e. the probability distribution has a 'heavy tail'.

In optics such distributions are obtained mainly from supercontinuum generation using laser light with faint (shot-noise-limited) fluctuations to pump a nonlinear medium. If a 'noisy' pump is used, one expects to have even more pronounced heavy tails.

In this work we used 'noisy' pump, obtained via parametric down-conversion, to produce tremendously fluctuating light from two different nonlinear processes: optical harmonics and supercontinuum generation. The generated light shows heavy-tailed statistics with extreme bunching (the bunching parameter g(2) being as high as 170) and extreme events (with photon numbers exceeding the mean values by three orders of magnitude).

Q 64.2 Fri 10:45 K 0.016

frequency-tripled photon generation in argon gas far beyond the paraxial regime — •rojiar penjweini[1,2], markus weber[1,2], markus sondermann[1,2], and gerd leuchs[1,2,3] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Erlangen, Germany — [3]Department of Physics, University of Ottawa, Ottawa, Canada

We investigate the generation of frequency-tripled photons under the condition of extremely tight focusing, which has not been explored in experiments before. As non-linear medium we use argon gas in the regime of normal dispersion. Our experiments show that the number of frequency-tripled photons under such conditions exhibits a fifth order dependence on the intensity of the fundamental beam. We argue that the observed frequency-tripled photons are generated through six-wave-mixing. We compare our experimental results to simulations, finding a good agreement between the simulation and experiments on the number of frequency-tripled photons as a function of focus size and pressure.

Q 64.3 Fri 11:00 K 0.016

A new definition for the Kerr nonlinearity parameter — •Izzatjon Allayarov[1], Swaathi Upendar[1], Markus A. Schmidt[2,3], and Thomas Weiss[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]Leibniz Institute of Photonic Technology, Germany — [3]Otto Schott Institute of Material Research, Friedrich Schiller University of Jena, Germany

Gas filled hollow-core photonic crystal fibers outperform conventional fibers in terms of their tuning capabilities. For instance, the linear dispersion and the nonlinear optical properties can be controlled through changing the temperature and the pressure [1]. Due to the finite cladding, the modes in such fibers are leaky, i.e., they radiate perpendicular to the fiber axis. Therefore, the electromagnetic fields of the modes grow exponentially with distance to the fiber center. Hence, the derivation of the Kerr nonlinearity parameter becomes questionable, since existing approaches rely on an arbitrary spatial truncation of the electromagnetic fields [2]. We present a new and more general derivation of the Kerr nonlinearity parameter that is based on the resonant state expansion [3]. Our approach provides the correct Kerr nonlinearity parameter independent of the spatial truncation. For leaky modes, we obtain a nonzero imaginary part of the Kerr nonlinearity parameter, providing nonlinear gain or loss. We will discuss about the impact of this novel result on the nonlinear pulse propagation.

[1] P. St. J. Russell et al., Nat. Photon. **8**, 278 (2014).
[2] S. Afshar V. and T. M. Monro, Opt. Express **17**, 2298 (2009).

[3] T. Weiss et al., Phys. Rev. B **96**, 045129 (2017).

Q 64.4 Fri 11:15 K 0.016

Generation of third harmonic and photon triplets in gas-filled hollow core photonic crystal fibre — •Andrea Cavanna[1], Cameron Okoth[1], Michael H. Frosz[1], Maria V. Chekhova[1,2,3], Gerd Leuchs[1,2], Nicolas Y. Joly[1,2], and Philip St.J. Russell[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]University of Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany — [3]Department of Physics, Moscow State University, 119991 Moscow, Russia

We present a single-ring photonic crystal fibre designed for phase-matched third harmonic generation from pump light at 1596 nm, as well as generation of photon triplets when pumped at 532 nm. The core region is surrounded by 12 capillaries with inner diameter approximately 6.7 μm and wall thickness 350 nm. The fiber guides, with losses below 1 dB/m, both broadband NIR radiation and visible light within a narrow spectral region around 532 nm. The 38 μm diameter core is filled with xenon gas, and the fibre offers convenient pressure-tunable dispersion and phase-matching for conversion from 532 to 1596 nm and vice-versa. We report generation of tunable third harmonic from an LP01-like pump mode to an LP03-like third harmonic mode as well as measurements of the luminescence at the single photon level for the reverse process.

Q 64.5 Fri 11:30 K 0.016

Coherent Raman gain suppression in gas-filled broadband-guiding photonic crystal fibres — •Manoj K. Mridha, Pooria Hosseini, David Novoa, and Philip St.J. Russell — Max Planck Institute for the Science of Light, Erlangen, Germany

The gain for stimulated Raman scattering (SRS) gets strongly suppressed when the rate of phonon creation (via pump-to-Stokes conversion) is equally compensated by the rate of phonon annihilation (via pump-to-anti-Stokes conversion). This occurs when the Raman coherence waves–synchronous oscillations of a large population of molecules–have identical propagation constants for both processes; i.e., they are phase-velocity matched. This phenomenon, first predicted more than half a century ago, has recently been demonstrated in the collinear geometry provided by a hydrogen-filled photonic crystal fibre pumped in the vicinity of its zero-dispersion wavelength. Here we report that Raman gain suppression is a universal feature of SRS in gas-filled hollow-core fibres and that it can strongly weaken SRS even under conditions of large phase mismatch, especially at high pump powers when it is normally assumed that nonlinear processes become more (not less) efficient. This counterintuitive behavior at high pump power implies the domination of Stokes growth in a different core mode compared to the pump (for example LP01/pump to LP11/ Stokes). These results have important implications for fibre-based Raman amplifiers, shifters, or frequency combs, especially for operation in the ultraviolet, where the Raman gain is very high.

Q 64.6 Fri 11:45 K 0.016

Transient Raman scattering in hollow-core photonic crystal fibers filled with gas mixtures — •Pooria Hosseini, David Novoa, and Philip St.J. Russell — Max Planck Institute for the Science of Light, Erlangen, Germany

Previous reports on stimulated Raman scattering (SRS) in mixtures of Raman-active and noble gases indicate that the addition of a dispersive buffer gas increases the phase-mismatch to higher-order Stokes/anti-Stokes sidebands, resulting in preferential conversion to the first few Stokes lines, accompanied by a significant reduction in Raman gain. Gas-filled hollow-core photonic crystal fibers (HC-PCFs) permit, however, operation in the so-called transient SRS regime, where the Raman gain is marginally reduced owing to the high pump intensities and long interaction lengths attainable. We report the generation of a dense cluster of Raman sidebands in the ultraviolet-visible region using a mixture of hydrogen-deuterium-xenon with 1-ns-long laser pulses of only 5 μJ energy at 532 nm. In addition, we show that, provided the dispersion can be precisely controlled, the effective Raman gain in gas-filled HC-PCF can actually be significantly enhanced when a buffer gas is added. This counterintuitive behavior occurs when the nonlinear coupling between the interacting fields is strong and can result in a performance similar to that of a pure Raman-active gas, but at much lower total gas pressure, allowing competing effects such as Raman backscattering to be suppressed.

Q 64.7 Fri 12:00 K 0.016

Waveguide-integrated single photon spectrometer based on tailored disorder — •Wladick Hartmann[1,2], Paris Varytis[3,4], Kurt Busch[3,4], and Wolfram Pernice[1,2] — [1]University of Münster, Institute of Physics, 48149 Münster, Germany — [2]University of Münster, CeNTech - Center for Nanotechnology, 48149 Münster, Germany — [3]Humboldt-University Berlin, Institute of Physics, Berlin, Germany — [4]Max-Born Institute, 12489 Berlin, Germany

Integrated nanophotonic circuits allow for realizing complex optical functionality in a compact and reproducible fashion through high-yield nanofabrication. Typically configured for single-mode operation in a single path, the optical propagation direction in such devices is determined by the waveguide layout which inherently requires smooth surfaces without scattering and restricts the device footprint to the limits of total internal reflection. Yet intentionally introducing disorder and scattering can be beneficial for the realization of novel nanophotonic components to overcome fabrication imperfections. In particular on-chip spectrometers may benefit from random disorder.

Here, as part of the priority program "Tailored Disorder" (SPP 1839), we utilize multi-path interference and the interaction of light with randomly oriented scatterers to realize broadband and narrow linewidth on-chip integrated spectrometers with small footprint. In combination with integrated superconducting nanowire single-photon detectors such devices allow for resolving optical spectra on the single photon level which is of interest for single-photon spectroscopy or quantum wavelength division multiplexing.

Q 64.8 Fri 12:15 K 0.016

Towards Integrated High-T$_c$ Superconducting Nanowire Hot Electron Bolometers — •Martin A. Wolff[1,2], Matvey Lyatti[1,2], Simone Ferrari[1,2], Carsten Schuck[1,2], and Wolfram H. P. Pernice[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany

The idea of exploiting the optical response of superconductors for nanophotonic applications such as bolometers, transition edge sensors and single-photon detectors is an active and rapidly growing field of research. Hot-electron bolometers (HEBs) feature very attractive performance such as low-noise and high-speed photon detection with applications in astronomy and quantum communication. However, cryogenic environments at temperatures below 4 K are inevitable for conventional low-temperature superconducting materials. Hence, there is an increasing interest for exploring the potential of high-T_c superconductors for this kind of application, thus significantly reducing the cryogenic requirements for operating HEBs.

Here we present the characterization of high-T$_c$ $YBa_2Cu_3O_{7-x}$ (YBCO) nanowires on a transparent $SrTiO_3$ (STO) substrate realized by a focused ion beam (FIB) milling technique. The fabricated nanowires are then used as bolometers to demonstrate their potential for photon detection.

Q 65: Nano-Optics and Biophotonics

Time: Friday 10:30–12:15 Location: K 0.023

Q 65.1 Fri 10:30 K 0.023

High resolution isotropic particle localization with a monolithic 4π parabolic mirror — •Lucas Alber[1,2], Martin Fischer[1,2], Florian Loosen[1,2], Bharath Srivathsan[1], Johannes Stehr[2], Markus Sondermann[1,2], and Gerd Leuchs[1,2,3] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics (IOIP), Friedrich-Alexander University Erlangen-Nuremberg (FAU), Germany — [3]Department of Physics, University of Ottawa, Canada

3D localization of single emitters forms the basis for high resolution localization microscopy. Localization is commonly done by imaging the emitter with a high-NA microscopic setup. In our work, we present the experimental demonstration of tracking a single trapped ion incorporating a monolithic parabolic mirror as the primary collection optic spanning almost 4π solid angle. Instead of imaging the emitter, we record the wavefront aberrations that are induced by displacements of the ion from the focal point of the mirror. For the measurement, we use a home-made single-photon sensitive Shack-Hartmann sensor that is based on a EMCCD camera. By moving the ion-trap mounted on a 3D translation piezo-stage, we can determine the tracking accuracy that amounts to a few tens of nanometer. Since we incorporate a 4π parabolic mirror, we are able to demonstrate a nearly isotropic 3D tracking resolution while at the same time we collect more than half of the photons emitted by the ion. The high 3D resolution and collection efficiency enables more accurate tracking of weak emitters embedded in a three-dimensional specimen.

Q 65.2 Fri 10:45 K 0.023

Coherent 2D fluorescence micro-spectroscopy — •Donghai Li[1], Sebastian Götz[1], Tobias Brixner[1,4], Verena Kolb[2], and Jens Pflaum[2,3] — [1]Institute for Physical and Theoretical Chemistry, University of Würzburg, 97074 Würzburg — [2]Experimental Physics VI, University of Würzburg, 97074 Würzburg — [3]Bavarian Center for Applied Energy Research (ZAE Bayern), Magdalene-Schoch-Str. 3, 97074 Würzburg — [4]Center for Nanosystems Chemistry (CNC), Theodor-Boveri-Weg, 97074 Würzburg

It is important to explore the relation between the microscopic morphology of the materials and their intrinsic ultrafast energy transfer processes. However, traditional ultrafast spectroscopy techniques provide only spatially averaged optical information. In order to study ultrafast processes on nanoscale, we combine femtosecond 2D spectroscopy with high NA microscopy. These functionalities are implemented by pairing fluorescence microscopy with phase and amplitude pulse shaping of few-cycle NIR pulses. The pulse shaper enables us not only to use the iterative pulse-compression algorithm to achieve nearly transform-limited sub-10fs laser pulses at the focus position, but also to create delay- and phase-controllable pules trains for phase-cycling process in third order signal measurements. The designed microscope setup with high NA objective focuses the broadband beam to the diffraction limit with a FWHM of 300 nm. The capability of the setup is demonstrated by obtaining spatially resolved 2D electronic spectroscopy of laterally nanostructured fluorinated zinc phthalocyanine film.

Q 65.3 Fri 11:00 K 0.023

Artifact-free XUV Coherence Tomography by one-dimensional phase retrieval — •Julius Reinhard[1], Silvio Fuchs[1,2], Martin Wünsche[1,2], Jan Nathanael[1], Johann Jakob Abel[1], Felix Wiesner[1], Christian Rödel[2], and Gerhard Paulus[1,2] — [1]Institute of Optics and Quantumelectronics, Jena, Germany — [2]Helmholtz Institute Jena, Germany

We report on major advances of XUV Coherence Tomography (XCT), which enable artifact-free three-dimensional imaging of nanoscale objects. XCT is the XUV equivalent of Optical Coherence Tomography (OCT). By using the broad bandwidth of high harmonics of femtosecond laser pulses (HHG) the axial resolution of XCT can reach a few nanometers [1]. However the typically modulated HHG spectra need to be transformed into a continuous spectrum by averaging HHG spectra generated with slightly different fundamental frequencies [2]. A challenge for XCT is the reconstruction of the sample structure from the measured intensity reflectivity, as the backtransform without knowledge of the phase information leads to artifacts in the reconstructed image. This problem has recently been addressed by implementing a novel one-dimensional phase retrieval algorithm, which has ultimately led to the artifact-free reconstruction of three dimensional samples [3].

[1] S. Fuchs et al., Scientific Reports 6, 20658 (2016)
[2] M. Wünsche et al., Optics Express 25, 6936 (2017)
[3] S. Fuchs et al. Optica 4, 903 (2017)

Q 65.4 Fri 11:15 K 0.023

Structured illumination quantum correlation microscopy — •Anton Classen[1,2], Joachim von Zanthier[1,2], Marlan O. Scully[3,4,5], and Girish S. Agarwal[3] — [1]Institut für Optik, Information und Photonik and — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen — [3]Texas A&M University, College Station, Texas 77843, USA — [4]Princeton University, Princeton, New Jersey 08544, USA — [5]Baylor University, Waco, Texas 76798, USA

We propose to use intensity correlation microscopy in combination with structured illumination to image quantum emitters that exhibit antibunching with a resolution reaching far beyond the Rayleigh limit. Combining intensity measurements and intensity autocorrelations of order m creates an effective PSF with the FWHM shrunk by a factor of $\sqrt{m}$ [1,2]. Structured Illumination microscopy [3] on the other hand introduces a resolution improvement by a factor of 2 by the principle of moiré fringes. We show that for linear low-intensity excitation and linear optical detection the simultaneous use of both techniques leads to an in theory unlimited resolution power with the improvement scaling favorably as $m + \sqrt{m}$ [4]. This yields the technique to be of interest for microscopy including imaging of biological samples. We present the underlying theory and simulations that demonstrate the increased resolution power, and point out requirements for an experimental implementation. [1] T. Dertinger et al., PNAS 106, 22287 (2009); [2] O. Schwartz et al., PRA 85, 033812 (2012); [3] M. G. Gustafsson, J. Micr. 198, 82 (2000); [4] A. Classen et al., Optica 4, 580 (2017)

Q 65.5 Fri 11:30 K 0.023

Exploring protein structure with cryogenic optical localization in three dimensions — Daniel Boening, •Franz Ferdinand Wieser, and Vahid Sandoghdar — Max Planck Institute for the Science of Light, Erlangen, Germany

Super-resolution optical microscopy has considerably advanced the study of cellular processes, but optical access to the molecular structure of proteins and biomolecular assemblies remains very limited. We have recently exploited the enhanced photostability of fluorophores at cryogenic temperatures to increase the number of detected photons, thus reaching a significantly higher signal-to-noise ratio compared to room-temperature measurements. Using this approach, cryogenic optical localization in three dimensions (COLD) is capable of determining the positions of several fluorescent sites within a single protein at Angstrom resolution [1]. We present results on imaging DNA Origami, the four binding sites of streptavidin and the conformational state of the Per-ARNT-Sim domain of the histidine kinase CitA. With its high spatial resolution COLD opens new possibilities for obtaining quantitative structure information from small to medium sized biomolecules and for correlative measurements with established imaging methods.

[1] S. Weisenburger et al., Nature Methods 14, 141-144 (2017).

Q 65.6 Fri 11:45 K 0.023

Multi-pass (electron) microscopy for low damage imaging applications. — •Thomas Juffmann — Ecole Normale Superieure, Paris, France

Specimen damage is often a limiting factor when it comes to imaging biological specimens (e.g. in cryogenic electron microscopy or optical live-cell imaging). Improved sensitivity and spatial resolution can be obtained employing quantum measurement strategies. A technologically viable and quantum optimal approach to measuring small phase shifts is to pass each probe particle through the specimen multiple times. Employing self-imaging cavities, this idea can be applied to widefield microscopy. We show post-selected optical birefringence and absorption measurements beyond the single pass shot-noise limit and discuss the applicability of multi-pass microscopy to cryo-EM. Our EM simulations show that multi-pass TEM allows for a tenfold damage reduction in imaging small proteins.

Q 65.7 Fri 12:00 K 0.023

Femtosecond 3D printing of an entire mini-microscope for neurobiological applications — •Chenyang Zhang[1], Simon Thiele[2], Simon Ristok[1], Ksenia Weber[1], Alois Herkommer[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institute of Technical Optics and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 9, 70569 Stuttgart, Germany

Using genetically modified mice, it is possible to observe the calcium ion transport in their brain cells. Green fluorescent protein with a peak luminescence at 510 nm indicates where the electric signals in the brain of mice flow after particular stimuli. Currently, a miniature microscope of the size in the range of centimeters is glued to the opened skull of the living mice. This allows for monitoring their thoughts. However, the size and weight of this microscope is hampering their motion and agility. Here, we demonstrate a 3D printed microscope imaging system including blue fluorescence excitation which allows for decent magnification and subsequent imaging. We utilize a femtosecond laser for printing. The size of the microscope is as small as a few mm, thus reducing the volume and the weight significantly.

Q 66: Quantum Effects (Entanglement and Decoherence)

Time: Friday 10:30–12:30 Location: K 1.013

Q 66.1 Fri 10:30 K 1.013

Forgetting and remembering – the story of Markovian and non-Markovian evolution — •Filip Wudarski — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Markovian and non-Markovian evolutions are one of key concepts in the theory of open quantum systems. Interestingly their sets do not exhibit convex structure, and it is possible to obtain non-Markovian evolution by mixing two Markovian ones, and vice versa. In this talk, we will present some basic concepts of Markovian and non-Markovian evolution and discuss the non-convex structure of the sets. We will refer to mathematical concepts and present their experimental implementation in photonic systems.

Q 66.2 Fri 10:45 K 1.013

Parametrization and optimization of Gaussian non-Markovian unravelings for open quantum dynamics — •Nina Megier[1], Walter T. Strunz[1], Carlos Viviescas[2], and Kimmo Luoma[1] — [1]Institut für Theoretische Physik, Technische Universität Dresden, Germany — [2]Departamento de Fisica, Universidad Nacional de Colombia, Bogota D.C., Colombia

A complete parametrization of diffusive stochastic Schrödinger equations in the Markovian regime is known (Wiseman, Diósi, Chem. Phys. 268, 91 (2001); Chia, Wiseman, PRA 84, 012119 (2011)). Changing these parameters allows control over the noise correlations driving the stochastic dynamics, which can be used to optimize the trajectories e.g. for entanglement detection (Viviescas et al., PRL 105, 210502 (2010); Guevara, Viviescas, PRA 90, 012338 (2014)).

A general non-Markovian Gaussian stochastic Schrödinger equation was recently postulated (Diósi, Ferialdi, PRL 113, 200403 (2014); Ferialdi, PRL 116, 120402 (2016)). Based on a microscopic model, we here derive a family of Gaussian non-Markovian stochastic Schrödinger equations with a single shot measurement interpretation (arXiv:1710.08359). The different unravelings correspond to different choices of squeezed coherent states, reflecting different measurement schemes on the environment. Interesting applications for quantum information tasks in the non-Markovian regime are given. In particular, by optimizing the squeezing parameters, we can tailor unravelings for optimal entanglement bounds or for environment-assisted entanglement protection.

Q 66.3 Fri 11:00 K 1.013

Rotational friction and thermalization of quantum rigid rotors — •Björn Schrinski, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

We present the general Markovian quantum master equation describing rotational decoherence, friction, diffusion, and thermalization of a rigid rotor in contact with a thermal environment. The master equation describes thermalization toward a Gibbs-like rotation state and gives rise to the rotational Fokker-Planck equation in its semiclassical limit. Its adequacy and applicability is demonstrated by studying the thermalization dynamics of the linear and the planar top. Possible applications include experimental tests of the quantum superposition principle involving the rotational degree of freedom [1], molecular quantum experiments in the field of ultracold chemistry [2], as well as the assessment of the thermodynamic efficiency of quantum rotor heat engines [3].

[1] B. Schrinski et al., J. Opt. Soc. Am. B 34, C1 (2017)
[2] S. A. Moses et al., Nat. Phys. 13, 13 (2017)
[3] A. Roulet et al., Phys. Rev. E 95, 062131 (2017)

Q 66.4 Fri 11:15 K 1.013

Thermalization as an invisibility cloak for fragile quantum superpositions — •Walter Hahn[1] and Boris Fine[1,2] — [1]Skolkovo Institute of Science and Technology, Skolkovo Innovation Centre, Nobel Street 3, Moscow 143026, Russia — [2]Institute for Theoretical Physics, Philosophenweg 12, 69120 Heidelberg, Germany

We propose a method for protecting fragile quantum superpositions in many-particle systems from dephasing by external classical noise. We call superpositions fragile if dephasing occurs particularly fast, because the noise couples very differently to the superposed states. The method consists of letting a quantum superposition evolve under the internal thermalization dynamics of the system, followed by a time-reversal manipulation known as Loschmidt echo. The thermalization dynamics makes the superposed states almost indistinguishable during most of the above procedure. We validate the method by applying it to a cluster of spins 1/2.

Q 66.5 Fri 11:30 K 1.013

Quantum description of lossy integrated photonic waveguide structures — •Lucas Teuber and Stefan Scheel — Institut für Physik, Universität Rostock, D-18055 Rostock, Germany

Integrated photonic waveguide structures created by the femtosecond laser direct-writting technique are a promising candidate for the implementation of quantum computational circuits [1]. The photons, as carriers of quantum information, are guided along the laser-written waveguides and can be exchanged between different waveguides via evanescent coupling. However, decoherence effects such as photon loss, dephasing, or path walk-off, have a detrimental effect on the ability to encode, transmit, and manipulate quantum information.

Here we report on our efforts to solve these problems. We derive a quantum mechanical description by discretizing the structures along the propagation direction and employing commutator-preserving input/output relations [2] for propagation and coupling. Additionally, we analyse different lossy waveguide structures to formulate suitable quantum eigenstates for optimal transport of quantum information.

[1] Meany, T. et al., Laser Photonics Rev. 9, 363 (2015).
[2] Scheel, S. and Buhmann, S.Y., Acta Phys. Slov. 58, 675 (2008).

Q 66.6 Fri 11:45 K 1.013

Jump-based Control of the Lipkin-Meshkov-Glick model — Sven Zimmermann, •Wassilij Kopylov, and Gernot Schaller — Institut für theoretische Physik, TU Berlin, Berlin, Germany

We apply a measurement based closed loop control scheme to the dissipative Lipkin-Meshkov-Glick model to affect the quantum phase transition[1-3]. Here we use the Wiseman-Milburn control scheme and apply it on the level of the master equation to the system dissipator [4]. Our interest lies in the steady state properties of the Lipkin-Meshkov-Glick system under the feedback action. We show, by calculating the averaged spin expectation values, that the considered control scheme changes the critical point of the phase transition. Furthermore, by investigating the waiting time distribution and the concurrence, we show, that the emission properties of the system and the entanglement can be strongly modified by the feedback control.

[1] H.J. Lipkin, N. Meshkov and A. Glick, Nucl. Phys., 62, 188 (1965)
[2] S. Morrison and A. S. Parkins PRL 100, 040403 (2008)
[3] W. Kopylov and T. Brandes, NJP 17, 103031 (2015)
[4] H. M. Wiseman and G. J. Milburn, Quantum Measurment Control, Cambrige University Press, Campridge (2010)
[5] G. Kießlich, C. Emary, G. Schaller and T. Brandes, NJP 14, 123036 (2012)

Q 66.7 Fri 12:00 K 1.013

Entanglement among degrees of freedom of a composite quasiparticle scattering by an impurity on a lattice — •Fumika Suzuki[1], Marina Litinskaya[2], and William G. Unruh[1] — [1]Department of Physics, University of British Columbia, Vancouver, V6T 1Z1, Canada — [2]Department of Chemistry, University of British Columbia, Vancouver, V6T 1Z1, Canada

We study scattering of a composite quasiparticle, which possesses a degree of freedom corresponding to relative separation between two bound particles, by a delta-like impurity potential on a one-dimensional discrete lattice. Different from a composite object in continuum space, for a composite quasiparticle on a discrete lattice, the entanglement between its relative and centre of mass coordinate degrees of freedom arises naturally due to inseparability of the two-particle Hamiltonian. One of the main focuses of our study is to investigate how this inseparability or the entanglement among degrees of freedom of the composite quasiparticle affects the way how it interacts with an external object such as an impurity. We also report the existence of excitation-impurity bound states whose energies are located in the continuum band. Finally, we discuss a change in the entanglement of a composite quasiparticle wave packet during a single impurity scattering and the decoherence effect on the interference pattern created by it.

Ref: F. Suzuki, M. Litinskaya and W. G. Unruh, Phys. Rev. B. 96, 054307 (2017).

Q 66.8 Fri 12:15 K 1.013

Exploring Fano interferometers towards entanglement detection — •Jörg Evers and Fabian Lauble — Max-Planck-Institut für Kernphysik, Heidelberg

Interferometry is an indispensable tool across all the natural sciences. Recently, we have proposed and implemented a new type of interferometer based on phase-sensitive Fano resonances. These Fano resonances appear if photons have two indistinguishable pathways from source to detector: either via a spectrally broad continuum channel, or via a spectrally narrow resonant bound state scattering channel. We have shown that these two channels can form interferometer arms [1], and experimentally demonstrated two different implementations of Fano interferometers in x-ray quantum optics [1,2]. Here, we review these Fano interferometers, and discuss their capabilities in particular related to the detection of single-photon mode entanglement [3].

[1] K. P. Heeg et al., *Interferometric phase detection at x-ray energies via Fano resonance control*, Phys. Rev. Lett. 114, 207401 (2015).

[2] K. P. Heeg et al., *Spectral narrowing of x-ray pulses for precision spectroscopy with nuclear resonances*, Science 357, 375 (2017).

[3] F. Lauble and J. Evers, *in preparation.*

Q 67: Precision Spectrosocopy VII (nuclear systems) (joint session A/Q)

Time: Friday 10:30–12:30 Location: K 1.016

Q 67.1 Fri 10:30 K 1.016

A direct nuclear laser excitation scheme for ^{229m}Th — •Lars von der Wense[1], Benedict Seiferle[1], Simon Stellmer[2], Johannes Weitenberg[3], Georgy Kazakov[2], Adriana Pálffy[4], and Peter G. Thirolf[1] — [1]Ludwig-Maximilians-Universität München, 85748 Garching, Germany — [2]Technische Universität Wien, 1040 Vienna, Austria — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [4]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

Direct nuclear laser excitation has been a long-standing goal. By today there is only one nuclear excitation known which would allow for direct laser excitation due to its exceptionally low energy of only a few eV above the ground state. This is the metastable first excited state in ^{229}Th. While direct nuclear laser excitation of ^{229}Th ions in a Paul trap is still hindered by insufficient knowledge of the exact isomeric energy value, here a new laser excitation scheme for neutral ^{229}Th atoms on a surface will be presented [1]. This excitation scheme circumvents the requirement of an improved knowlede of the isomeric energy, thereby paving the way for nuclear laser spectroscopy of ^{229m}Th. It is making use of the recently detected internal conversion decay channel of the isomeric state [2] in combination with a short isomeric lifetime [3].

[1] L. v.d.Wense et al., PRL 119, 132503 (2017).
[2] L. v.d.Wense et al., Nature 533, 47-51 (2016).
[3] B. Seiferle et al., PRL 118, 042501 (2017).

Supp. by DFG (TH956/3-2) and Horizon 2020 (664732 "nuClock").

Q 67.2 Fri 10:45 K 1.016

Towards a precise energy determination of the ^{229}Th nuclear clock transition — •Benedict Seiferle, Lars v.d. Wense, and Peter G. Thirolf — LMU München, Am Coulombwall 1, 85748 Garching

The first isomeric excited nuclear state of ^{229}Th (denoted with ^{229m}Th) exhibits the lowest transition energy in nuclear physics which has been measured indirectly to be 7.8(5) eV. The uniquely low transition energy which corresponds to a wavelength of approximately 160 nm makes it possible to drive the transition with lasers. This in turn may pave the way for a long list of interesting applications (such as a nuclear optical clock) which has so far been hindered by the rather large uncertainty in the reported energy value. In this talk an experimental scheme is presented that uses internal conversion electrons which are emitted in the ground-state decay of ^{229m}Th [1,2] and first results are shown. With these measurements a precise and direct determination of the excitation energy is in reach.

[1] L. v.d. Wense et al., Nature 533, 47-51 (2016).
[2] B. Seiferle et al., PRL 118, 042501 (2017).

This work was supported by the European Union's Horizon 2020 research and innovation programme under grant agreement 664732 "nuClock" & by DFG Grant No. Th956/3-2.

Q 67.3 Fri 11:00 K 1.016

Laser spectroscopic characterization of the nuclear clock isomer ^{229m}Th — •Johannes Thielking[1], Maksim V. Okhapkin[1], Przemysław Głowacki[1], David-Marcel Meier[1], Lars von der Wense[2], Benedict Seiferle[2], Christoph E. Düllmann[3,4,5], Peter G. Thirolf[2], and Ekkehard Peik[1] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Ludwig-Maximilians-Universität München, 85748 Garching, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [4]Helmholtz-Institut Mainz, 55099 Mainz, Germany — [5]Johannes Gutenberg-Universität, 55099 Mainz, Germany

The thorium-229 nucleus possesses a unique first excited state at an energy of only about 7.8 eV, coupled to the ground state by a transition with a natural linewidth in the mHz range. This transition can be used as a reference for an optical clock that is highly immune to field-induced frequency shifts and as a sensitive probe of temporal variations of fundamental constants. Despite many experimental efforts, fundamental properties of the isomer were still unknown. In this presentation we report on the first measurement of the nuclear moments and the mean square charge radius of the isomer [1]. This was achieved via high-resolution spectroscopy of the hyperfine structure of trapped ^{229}Th^{2+} ions using two-step laser excitation. Our results yield a key feature in the ongoing experimental search for the direct optical excitation of the nuclear transition, as well as the future nuclear clock operation.

[1] J. Thielking et al., arXiv preprint arXiv:1709.05325 (2017).

Q 67.4 Fri 11:15 K 1.016

Hyperfine structure and isomeric shifts in ^{229}Th^{2+} — •Robert A. Müller[1,2], Andrey V. Volotka[3], Stephan Fritzsche[2,4], and Andrey Surzhykov[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany — [3]Helmholtz-Institute Jena, Germany — [4]Friedrich-Schiller-Universität Jena, Germany

In the past decade systems that are sensitive to possible time variations of α attracted much interest [1]. Besides the comparison of two atomic clocks, nuclear transitions could be used for the search of such variations. The isotope ^{229}Th is a particularly suitable candidate, because of its low lying isomeric state ^{229m}Th which is accessible to optical lasers. The sensitivity of the ^{229}Th$\rightarrow^{229m}$Th transition to variations of α has been only estimated so far [2]. For a more accurate determination of this sensitivity and for the analysis of related experiments precise knowledge about the nuclear moments, as well as the isomeric shift of electronic levels is needed. In this contribution we will, therefore, discuss highly accurate calculations for the hyperfine structure of the ^{229}Th^{2+} ion. We used these results to precisely determine the nuclear moments of the nuclear isomer ^{229m}Th. Moreover we calculated the isomeric shift of electronic levels in Th^{2+}. All calculations have been performed using the multi-configurational Dirac-Fock method as well as a combination of configuration interaction and many-body perturbation theory.

[1] J. K. Webb *et al.*, Phys. Rev. Lett. **87**, 091301 (2001)
[2] V. V. Flambaum, Phys. Rev. Lett. **97**, 092502 (2006)

Q 67.5 Fri 11:30 K 1.016

Towards coherent control of the ^{229}Th isomeric transition in VUV-transparent crystals — •Brenden Nickerson and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Current efforts in the development of a nuclear frequency standard based on the isomeric state of ^{229m}Th at approx. 7.8 eV have been centered around precisely determining its energy. The unique lowest transition in the ^{229}Th nucleus with frequency in the vacuum ultraviolet (VUV) range and very narrow linewidth promises enhanced precision and amazing stability [1]. A very exact measurement of the isomeric transition energy has been elusive, with the first confirmation of the level decay coming only recently [2].

Here, we investigate collective effects that may allow for coherent control of the isomeric transition in ^{229}Th:CaF_2 VUV-transparent crystals. The collectively enhancement scattering in forward direction is considered [3]. Starting from this setup, we investigate the effect of pulsed lasers, coincident pulses, different pulse phases and of magnetic fields for the intensity spectrum. By taking advantage of such effects we aim to design a more sensitive nuclear excitation scheme to resolve not only the transition energy but provide a clear signature of the excitation.

[1] W. G. Rellergert *et al.*, Phys. Rev. Lett. 104, 200802 (2010).
[2] L. von der Wense *et al.*, Nature 533, 47-51 (2016).
[3] W.-T. Liao *et al.*, Phys. Rev. Lett. 109, 262502 (2012).

Q 67.6 Fri 11:45 K 1.016

Laser spectroscopy of the heaviest actinides — •S. Raeder[1,2], D. Ackermann[2,3], H. Backe[4], M. Block[1,2,4], B. Cheal[6], P. Chhetri[2,5], C. E. Düllmann[1,2,4], M. Eibach[2,7], J. Even[8], R. Ferrer[9], F. Giacoppo[1,2], S. Götz[1,2,4], F.P. Hessberger[2,5], O. Kaleja[2,4,10], J. Khuyagbaatar[1,2], P. Kunz[11], M. Laatiaoui[9], F. Lautenschläger[2,5], W. Lauth[4], L. Lens[2,4], N. Lecesne[3], A. K. Mistry[1,2], E. Minaya Ramirez[12], Th. Walther[5], A. Yakushev[1,2], and Z. Zhang[13] — [1]Helmholtz-Institut Mainz — [2]GSI — [3]GANIL — [4]JGU Mainz — [5]TU Darmstadt — [6]Uni of Liverpool — [7]Universität Greifswald — [8]KVI-CART, Uni of Groningen — [9]KU-Leuven — [10]MPIK — [11]TRIUMF — [12]IPNO — [13]IMP Lanzhou

Laser spectroscopy of transfermium elements with $Z>100$ probes the influence of electron correlation, relativistic and QED effects on the atomic shell structure. These studies are hampered by low production rates and the fact that atomic information is initially available only from theoretical predictions. Applying the sensitive Radiation Detected Resonance Ionization Spectroscopy technique at the SHIP velocity filter in GSI, optical transitions in the element nobelium (Z=102) were detected for the first time. Besides the characterization of a strong optical ground-state transition in the isotopes ^{252,253,254}No, Rydberg states were measured enabling the extraction of the first ionization potential of nobelium with a high precision. These results will be discussed as well as the prospects for future investigations involving the study of additional nobelium isotopes and the exploration of the atomic structure of the next heavier element, lawrencium (Z=103).

Q 67.7 Fri 12:00 K 1.016

Development of an Ion Mobility Spectrometer for Mobility Measurement of Actinides — •E. Rickert[1,3], H. Backe[3], M. Block[1,2,3], Ch. E. Düllmann[1,2,3], T. Kron[1,2], M. Laatiaoui[1,2,4], W. Lauth[3], S. Lohse[1], F. Schneider[1,3], and S. Raeder[1,2] — [1]Helmholtz-Institut Mainz — [2]GSI — [3]JGU Mainz — [4]KU Leuven

Ion mobility measurements are a powerful tool to investigate ion-atom interaction potentials. Their sensitivity to the electronic configuration has been demonstrated for many elements across the periodic table. Especially for heavy elements, the impact of relativistic effects on the electron configuration may lead to deviations in the periodicity, hence to distinct ion mobilities [Laatiaoui2012] as recently proven in the lanthanide region. A conceptual design for an ion mobility spectrometer is being developed to enable systematic ion mobility spectrometry also across the actinide series. Actinide ions will be created via a two-step photoionization in argon gas. This will allow an element-selective detection. In the talk, the current status and future plans are presented.

[Laatiaoui2012]:Laatiaoui, M. et al., EPJD (2012) 66:232

Q 67.8 Fri 12:15 K 1.016

Desorption enthalpy studies of the heaviest actinides for laser spectroscopic investigations — •T. Murböck[1], D. Ackermann[1,2], H. Backe[3], M. Block[1,3,4], B. Cheal[5], P. Chhetri[1,6], Ch. E. Düllmann[1,3,4], M. Eibach[1,7], J. Even[8], R. Ferrer[9], F. Giacoppo[1,4], S. Götz[1,3,4], F.P. Hessberger[1,4], O. Kaleja[1,3,10], J. Khuyagbaatar[1,4], P. Kunz[11], M. Laatiaoui[1,4], F. Lautenschläger[1,6], W. Lauth[3], L. Lens[1,3], N. Lecesne[2], A. K. Mistry[1,4], E. Minaya Ramirez[12], S. Raeder[4], P. Van Duppen[9], Th. Walther[6], A. Yakushev[1,4], and Z. Zhang[13] — [1]GSI — [2]GANIL — [3]Universität Mainz — [4]HI Mainz — [5]University of Liverpool — [6]TU Darmstadt — [7]Universität Greifswald — [8]KVI-CART, University of Groningen — [9]KU-Leuven — [10]MPIK — [11]TRIUMF — [12]IPN Orsay — [13]IMP Lanzhou

To probe the atomic shell structure of the heaviest actinides with Z>100, the Radiation Detected Resonance Ionization Spectroscopy (RADRIS) technique is applied at SHIP at GSI. After production in high-energy fusion-evaporation reactions the recoil ions are stopped in a buffer-gas cell and collected onto a filament. Subsequent thermal evaporation as neutral atoms allows to probe the atomic structure using laser spectroscopy. The desorption enthalphy of these elements crucially determines the efficiency of the evaporation and the RADRIS method. In this talk, evaporation of nobelium (Z=102) and lawrencium (Z=103) from tantalum is revisited. Prospects for desorption studies from a larger variety of surfaces to extend laser-spectroscopic investigations to heavier elements will be discussed.

Q 68: Quantum Information (Concepts and Methods) V

Time: Friday 10:30–12:30 Location: K 1.019

Q 68.1 Fri 10:30 K 1.019

Bounds on absolutely maximally entangled states from shadow inequalities, and the quantum MacWilliams identity — •Felix Huber[1], Christopher Eltschka[2], Jens Siewert[3], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, D-57068 Siegen, Germany — [2]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [3]Departamento de Quimica Fisica, Universidad del Pais Vasco UPV/EHU, E-48080 Bilbao, Spain

A pure multipartite quantum state is called absolutely maximally entangled (AME), if all reductions obtained by tracing out at least half of its parties are maximally mixed. Maximal entanglement is then present across every bipartition. The existence of such states is in many cases unclear. With the help of the weight enumerator machinery known from quantum error correction and the generalized shadow inequalities, we obtain new bounds on the existence of AME states in dimensions larger than two. To complete the treatment on the weight enumerator machinery, the quantum MacWilliams identity is derived in the Bloch representation. Finally, we consider AME states whose subsystems have different local dimensions, and present an example for a 2x3x3x3 system that shows maximal entanglement across every bipartition.

Q 68.2 Fri 10:45 K 1.019

Truncated moment sequences and the entanglement problem — Fabien Bohnet-Waldraff[1], Olivier Giraud[2], and •Daniel Braun[1] — [1]Institute for theoretical Physics, University Tübingen — [2]LPTMS, University Paris-Saclay and CNRS

The "entanglement problem" is to decide whether a given quantum state of a composite system is is entangled over a chosen partition or not. We show that it can be mapped to the "truncated moment problem" studied in mathematics, for which recently a complete solution was found in the sense of a necessary and sufficient condition. It gives rise to a hierarchy of semi-definite programs corresponding to state extensions with polynomial constraints, and the positive-partial-transpose criterion as a first step, that generalizes and unifies on an abstract level previous approaches such as the Doherty- Parrilo-Spedalieri hierarchy. Flat extensions play a crucial role and are a systematic ingredient that allows us to prove separability of a state and obtain its explicit decomposition into a convex sum of product states. The approach is very flexible and general. It can accomodate naturally missing experimental data, symmetries, and subsystems of different dimensions.

Q 68.3 Fri 11:00 K 1.019

Characterising the distribution of quantum correlations via

mutually unbiased bases — •Ali Asadian — TU Wien, Vienna

We know that an N-body quantum state can be reconstructed via the minimal sets of N-body probabilities corresponding to mutually unbiased bases (MUBs) measurements. It is useful to seek for a formulation where the state can be characterised via local one-body sets of MUBs and the k-body MUBs accounting for the correlations. For example, in the case of bipartite system this includes a complete set of local one-body MUBs for estimating the each party*s reduced states and an associated set of 2-body MUBs qualified for a complete estimation of 2-body correlations. I believe that such a classification gives a significant insight into the nature of the information content in N-body quantum states and how it is shared among the k-body correlations. A relevant property is the entanglement monogamy. It has been shown that anti-commutativity yields entanglement monogamy.

Q 68.4 Fri 11:15 K 1.019

Entanglement robustness of symmetric multiqubit states — •Antoine Neven, John Martin, and Thierry Bastin — CESAM Research Unit, Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, 4000 Liège, Belgium

Detecting the entanglement of a multipartite pure state is a task that can now be addressed using various tools, such as for example, negativity or generalised concurrences. Realising the same task with a mixed state is however still a challenge today. In a situation where some of the parties of a multipartite entangled pure state are lost, the question arises whether the residual mixed state keeps some of the initial entanglement. In this context, entangled pure states that after partial trace keep some entanglement are said to be robust against party loss and those that lose all entanglement (i.e. become separable) are said to be fragile against party loss. In this talk, we investigate the entanglement robustness against party loss of symmetric multiqubit states. We identify all the fragile states for the loss of 1 qubit and show that these fragile states exhibit a particular symmetry and are all SLOCC-equivalent. We also study robustness properties for multiple parties loss and treat exhaustively the case of symmetric states of 4 qubits.

Q 68.5 Fri 11:30 K 1.019

Characterization of quantum circuit in quantum-classical algorithms — •Andreas Woitzik[1], Panagiotis Kl. Barkoutsos[2], Ivano Tavernelli[2], Filip Wudarski[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [2]IBM Research ZRL, Rüschlikon, Switzerland

Recent advances in hybrid (quantum-classical) algorithms allow us to infer the ground states of Hamiltonians which are of relevance in quantum chemistry or for involved optimization problems. A possible approach is defined by a systematic search on the full Hilbert space via the sequential application of single-qubit rotations and multi-qubit entangling gates.

First results indicate that the high dimensionality of the molecular Hilbert space necessitates a large number of such entanglement blocks. The thus imposed critical circuit depth on state of the art quantum architectures with limited coherence times implies important restrictions for possible applications.

In order to reduce the number of gate operations, we investigate different entanglement schemes and evaluate their properties by means of a set of descriptors that includes entanglement quantifiers, site occupation, and convergence efficiency.

Q 68.6 Fri 11:45 K 1.019

Quantum states with a positive partial transpose are useful for metrology — •Géza Tóth[1,2,3] and Tamás Vértesi[4] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [4]Institute for Nuclear Research, Hungarian Academy of Sciences, P.O. Box 51, H-4001 Debrecen, Hungary

We show that multiparticle quantum states that have a positive partial transpose with respect to all bipartitions of the particles can outperform separable states in linear interferometers. We introduce a powerful iterative method to find such states. We present some examples for multipartite states and examine the scaling of the precision with the particle number. Some bipartite examples are also shown that possess an entanglement very robust to noise. We also discuss the relation of metrological usefulness to Bell inequality violation. We find that quantum states that do not violate any Bell inequality can outperform separable states metrologically. We present such states with a positive partial transpose, as well as with a non-positive positive partial transpose.

Q 68.7 Fri 12:00 K 1.019

Estimating the amount of spatial correlations in quantum dynamics — •Lukas Postler[1], Ángel Rivas[2], Daniel Nigg[1], Esteban Martinez[1], Alexander Erhard[1], Roman Stricker[1], Philipp Schindler[1], Thomas Monz[1], Rainer Blatt[1,4], Miguel Angel Martín-Delgado[2], and Markus Müller[3] — [1]Institut für Experimentalphysik, Unviersität Innsbruck, Technikerstr. 25, A-6020 Innsbruck, Austria — [2]Departamento de Física Teórica I, Universidad Complutense — [3]Department of Physics, College of Science, Swansea University, Singleton Park, Swansea SA2 8PP, United Kingdom — [4]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria

Correlations in the dynamics of quantum mechanical systems are involved in many phenomena, like sub - and superradiance.Furthermore, correlations between errors also play an important role in quantum error correction schemes. A measure to quantify these correlations was introduced in [1]. To increase the applicability of this measure to intermediately and large sized quantum systems, more efficient methods to estimate spatial correlations in quantum dynamics are presented. An experimental realisation of the protocols in an trapped ion quantum information processor will be presented.

[1] A. Rivas and M. Müller, New J. Phys. 17, 062001 (2015).

Q 68.8 Fri 12:15 K 1.019

Initial System-Environment Correlations via the Transfer Tensor Method — Maximilian Buser[1,2], •Javier Cerrillo[1], Gernot Schaller[1], and Jianshu Cao[2] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, D-10623 Berlin, German — [2]Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA

Open quantum systems exhibiting initial system-environment correlations are notoriously difficult to simulate. We point out that given a sufficiently long sample of the exact short-time evolution of the open system dynamics, one may employ transfer tensors for the further propagation of the reduced open system state. This approach is numerically advantageous and allows for the simulation of quantum correlation functions in hardly accessible regimes. We benchmark this approach against analytically exact solutions and exemplify it with the calculation of emission spectra of multichromophoric systems as well as for the reverse temperature estimation from simulated spectroscopic data. Finally, we employ our approach for the detection of spectral signatures of electromagnetically-induced transparency in open three-level systems.

Q 69: Post-Deadline Session

Time: Friday 10:30–11:30 Location: K 1.020

Q 69.1 Fri 10:30 K 1.020

Experimental Evidence of Quantum Radiation Reaction in Aligned Crystals — •Tobias Wistisen and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Radiation reaction is the influence of the electromagnetic field emitted by a charged particle on the dynamics of the particle itself. Classical theoretical approaches to radiation reaction lead to physically inconsistent equations of motion. In addition, radiation-reaction effects have never been measured, which has prevented a complete understanding of this problem [1]. Here I will talk about experimental results obtained to address this issue [2]. We measured radiation emission spectra from ultrarelativistic positrons in silicon in a regime where both quantum and radiation-reaction effects dominate the dynamics of the positrons. We found that each positron emits multiple photons with energy comparable to its own energy, revealing the importance of quantum photon recoil. Moreover, the shape of the emission spectra indicates that photon emissions occur in a nonlinear regime where positrons absorb several quanta from the crystal field. This experiment is the first fundamental test of quantum electrodynamics in a new regime where the dynamics of charged particles is strongly influenced not only by the external electromagnetic fields but also by the radiation-field generated by the charges themselves and where each photon emission potentially reduces the energy of the charge by a significant amount.

[1] A. Di Piazza et al., Rev. Mod. Phys. 84, 1177 (2012)

[2] T. N. Wistisen, A. Di Piazza, H. V. Knudsen, and U. I. Uggerhøj, arXiv:1704.01080, 2017.

Q 69.2 Fri 10:45 K 1.020

Towards spin-photon entanglement in single ions trapped in UV fiber cavities — Pascal Kobel, Kilian Kluge, •Jonas Schmitz, Maximilian Zawierucha, Hendrik M. Meyer, and Michael Köhl — Physikalisches Institut, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany

Trapped ions coupled to optical cavities are among the most promising candidates for entanglement generation and distribution in quantum networks. We demonstrate single photon generation of a trapped ytterbium ion coupled to an optical fiber cavity as well as coherent qubit control. This paves the way for spin-photon entanglement generation at scalable rates.

Additionally, the setup of a novel dual-species ion trap will be presented. It incorporates macroscopic cavity mirrors designed for transitions at 370 nm (Yb^+) and 493 nm (Ba^+). Avoiding macroscopic amounts of hydrocarbons inside the vacuum chamber, the cavity finesse shows no degradation on a timescale of months, contrary to earlier experiments employing UV cavities.

Q 69.3 Fri 11:00 K 1.020

Correlated photon-pair emission from a cw-pumped Fabry-Perot microcavity — •Thorsten F. Langerfeld, Hendrik M. Meyer, and Michael Köhl — Physikalisches Institut, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany

The generation of correlated photons is an important milestone in fundamental test of quantum mechanics and in the quest to interconnect remote quantum systems with the goal of creating quantum networks. For the latter, a tunable photon pair source, which can be tailored to the physical properties of the network nodes is desirable. For that purpose, we study a dispersion-compensated high-finesse optical Fabry-Perot microcavity under high-intensity cw pumping. The Kerr non-linearity in the optical coatings causes a spontaneous four-wave mixing process, triggered by vacuum fluctuations of the unoccupied cavity modes, which leads to the emission of time-correlated photon pairs, which are shifted in frequency by ± 1 free spectral range relative to the pump frequency. The ease of the experimental setup, e.g. avoiding a phase matching condition by employing a sub-wavelength thick nonlinear medium, and the principal tunability of the wavelengths and bandwidths of the created photon pair make the scheme an attractive candidate for a photon-pair source with application in hybrid quantum systems in which wavelength has to be bridged between dissimilar systems.

Q 69.4 Fri 11:15 K 1.020

Trident pair-production in strong-field QED: pulse shape dependence — •Uwe Hernandez Acosta and Burkhard Kämpfer — Institute of Radiation Physics, Helmholtz-Zentrum Dresden-Rossendorf

We present calculations of trident pair (e+,e-) production in laser-electron collisions within the framework of strong-field QED. The Furry picture is suitable to study the impact of the beam shape. Analog to Compton and Breit-Wheeler processes, rich structure patterns can emerge in various observables reflecting pulse features. The trident process is interesting as first step in seeded cascades as well-controlled QED background.

Q 70: Ultracold Atoms II (joint session Q/A)

Time: Friday 10:30–12:30 Location: K 1.022

Q 70.1 Fri 10:30 K 1.022

Quantum optimal control for fast atom transport in an optical lattice — •Manolo Rivera[1], Thorsten Groh[1], Natalie Thau[1], Carsten Robens[1], Wolfgang Alt[1], Dieter Meschede[1], Antonio Negretti[2], Tommaso Calarco[3], Simone Montagero[3], and Andrea Alberti[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany — [3]Institut für komplexe Quantensysteme, Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany

We realize fast atom transport in a polarization-synthesized state-dependent optical lattice reaching transport times down to the harmonic oscillator period of around $20\mu s$ over one lattice site ($\approx 0.5\mu m$). Atom transport at such durations reaches the quantum speed limit that we have obtained from numerical simulations of the Schrödinger equation. The transport operations are computed using optimal control theory and reach high fidelities, meaning that the atoms prepared in the ground state remain there after the transport. This is experimentally confirmed by measuring the excitation spectrum of the transported atoms by means of microwave sideband spectroscopy. The current experiment is based on an open-loop approach where the transport operations are theoretically computed. A closed-loop approach using the optimization algorithm directly in the experimental sequence allows us to further improve the fidelity of the optimal control transport operations.

Q 70.2 Fri 10:45 K 1.022

Tuning the Scattering Length by Periodic Modulation — •Christoph Dauer, Axel Pelster, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

We consider the scattering problem of two ultracold particles with a small time-periodic modulation of the attractive potential, which can be achieved by using a Feshbach resonance. The steady state is described by the Floquet formalism, which leads to a recurrence formula for an effective scattering length a_{eff}. For frequencies corresponding to the bound-state of the potential without driving, we observe strong resonances, which allow the tuning to very large positive and negative values of a_{eff} with relatively small imaginary parts.

Q 70.3 Fri 11:00 K 1.022

A two-species five-beam magneto-optical trap for highly magnetic Er and Dy atoms — •Arno Trautmann[1], Philipp Ilzhöfer[1,2], Gianmaria Durastante[1,2], Alexander Patscheider[1,2], Manfred Mark[1,2], and Francesca Ferlaino[1,2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Austria — [2]Institut für Experimentalphysik und Zentrum für Quantenoptik, Universität Innsbruck, Austria

We report on the first realization of a two-species magneto-optical trap (MOT) for erbium and dysprosium. The MOT operates on an intercombination line for the respective species. Owing to the narrow-line character of such a cooling transition and the action of gravity, we demonstrate a novel trap geometry employing only five beams in orthogonal configuration. We observe that the mixture is cooled and trapped very efficiently, with up to 5×10^8 Er atoms and 10^9 Dy atoms at temperatures of about $10\,\mu$K. Our results offer an ideal starting condition for the creation of a dipolar quantum mixture of highly magnetic atoms.

Q 70.4 Fri 11:15 K 1.022

Few bosons in a double well — •Frank Schäfer[1], Miguel Bastarrachea[1], Axel U. J. Lode[2,3], Laurent de Forges de Parny[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]Wolfgang Pauli Institute c/o Faculty of Mathematics, University of Vienna, Oskar-Morgenstern Platz 1, 1090 Vienna, Austria — [3]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria

We investigate the spectral and dynamical properties of interacting bosons in a double well. A combination of exact diagonalization with a multi-configurational time-dependent Hartree approach allows us to analyse the time evolution of two- and three- particle states for variable initial conditions, and furthermore subject to (a-)diabatic switching of the tunnelling barrier. We discuss first results for the particles initially prepared at the ground state or at the saddle-point energy, and contrast single- vs. many-particle aspects of the dynamics.

Q 70.5 Fri 11:30 K 1.022

Diffusion of Ultracold Atoms Coupled to tailored Bath — •Daniel Adam, Tobias Lausch, Daniel Mayer, Felix Schmidt, Quentin Bouton, and Artur Widera — TU Kaiserslautern, Department of Physics, Kaiserslautern, Germany

Diffusion is an essential phenomenon in nature, occurring in various systems from biological cells to traffic models. Ultracold atoms are ideal model systems to go beyond the mere observation of single particle diffusion, and to engineer the surrounding baths by external fields.

Here, we consider the diffusion of single neutral atoms trapped in a periodic potential and coupled to a near-resonant light field forming the bath. This bath defines both fluctuations as well as the diffusion coefficient via the laser cooling properties of the optical molasses. The diffusion coefficient significantly determines the dynamics of a diffusing tracer, thus its knowledge is of central importance to understand the fundamental diffusion. I will present a method to measure the diffusion coefficient directly with single Cs-atoms confined in a harmonic potential. This method is similar to the method of tethered particle motion known for the observation of DNA dynamics.

Precise knowledge of the diffusion coefficient as a function of external experimental parameters opens the route for quantitative measurements of diffusion in complex potential landscapes or non-equilibrium situations.

Q 70.6 Fri 11:45 K 1.022

Revealing Quantum Statistics with a Pair of Distant Atoms — Christian Roos[1], •Andrea Alberti[2], Dieter Meschede[2], Philipp Hauke[3], and Hartmut Häffner[4] — [1]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, Otto-Hittmair-Platz 1, 6020 Innsbruck, Austria — [2]Institut für Angewandte Physik der Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany — [3]Institut für Theoretische Physik, Universität Innsbruck, Technikerstraße 21a, 6020 Innsbruck, Austria — [4]Department of Physics, University of California, Berkeley, California 94720, USA

Quantum statistics have a profound impact on the properties of systems composed of identical particles. At the most elementary level, Bose and Fermi quantum statistics differ in the exchange phase, either 0 or π, which the wave function acquires when two identical particles are exchanged. I will report on a scheme to directly probe the exchange phase with a pair of massive particles by physically exchanging their positions [1]. I present two protocols realizing this scheme where the particles always remain spatially well separated, thus ensuring that the exchange contribution to their interaction energy is negligible and that the detected signal can only be attributed to the exchange symmetry of the wave function. Finally, I discuss possible implementations using a pair of atoms confined in polarization-synthesized optical lattices or trapped ions forming a one-dimensional quantum rotor.

[1] C. F. Roos, A. Alberti, D. Meschede, P. Hauke, and H. Häffner, Phys. Rev. Lett. **119**, 160401 (2017).

Q 70.7 Fri 12:00 K 1.022

Signatures of indistinguishability in bosonic many-body dynamics — •Tobias Brünner[1], Gabriel Dufour[1,2], Alberto Rodriguez[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität-Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität-Freiburg, Albertstraße 19, D-79104 Freiburg, Germany

Many-body interference occurs as a fundamental process during the evolution of a quantum system consisting of two or more indistinguishable particles. The (measurable) consequences of this interference, as a function of the particles' mutual indistinguishability, was studied for non-interacting photons transmitted through beam-splitter arrays. However, the role of many-body interference in the dynamics of interacting particles, e.g. cold atoms in optical lattices, had so far remained unclear. We identify a quantifier of the particles' mutual indistinguishability attuned to time-continuously evolving systems of (interacting) particles, which predicts the dynamical behaviour of observables influenced by genuine few-body interference. Our measure allows a systematic exploration of the role of many-body interference in the non-, weakly, and strongly interacting regimes.

Q 70.8 Fri 12:15 K 1.022

Survival probability of coherent states in regular regimes — •Miguel A. Bastarrachea-Magnani[1], Sergio A. Lerma-Hernández[2], Jorge Chávez-Carlos[3], Lea F. Santos[4], and Jorge G. Hirsch[3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany — [2]Facultad de Física, Universidad Veracruzana, Xalapa, México — [3]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, México — [4]Department of Physics, Yeshiva University, New York, USA

We study the behavior of coherent states under unitary quantum dynamics in systems with one and two degrees of freedom. To this end, we employ the Dicke Hamiltonian, a paradigmatic model of quantum optics. Within the regular regime of the spectrum, the distribution of the coherent states in the eigenstate basis consists of quasi-harmonic sub-sequences of energies with gaussian weights. This allows to derive analytical expressions for the survival probability of the coherent states. The analytical expressions describe the time evolution in agreement with numerical results up to the decay of the survival probability oscillations. We explore how this decay rate is related to the anharmonicity of the spectrum, and, for the chaotic regime of the Dicke model, to interference terms due to the contributions of different subsequences of eigenstates to the coherent states. Moreover, we correlate the dynamics of the coherent states with the classical limit of the model, to elucidate how these interference terms are related to the onset of chaos in the spectrum. Since most bounded Hamiltonians have a regular regime at low energies, the approach has broad applicability.

Q 71: Precision Measurements and Metrology (Optical Clocks) (joint session Q/A)

Time: Friday 10:30–12:15 Location: K 2.013

Q 71.1 Fri 10:30 K 2.013

Precision Paul trap for frequency metrology with Coulomb crystals — •André P. Kulosa, Dimitri Kalincev, Jan Kiethe, Tabea Nordmann, Nimrod Hausser, Chih-Han Yeh, Alexandre Didier, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Deutschland

We report on our new scalable precision ion trap capable of trapping Coulomb crystals with 100 ions and more in each of the trap segments. We demonstrate that the excellent control of 3D excess micromotion over a single ion [1] also holds for a linear chain of 14 ions via spatial imaging with atomic resolution. We find that in a trap segment of our ion trap the time dilation shift due to axial micromotion is as low as 10^{-19} over a range of 400μm and below 10^{-18} within 2mm. After quench-assisted cooling of a single ^{172}Yb$^+$ ion to its motional ground state, we observe a heating rate of less than 1 phonon/s and in total a $1/f$ dependence on electric field noise induced by fluctuating charges on the trap electrodes. Based on further experimental investigations of the trap environment, we derive an uncertainty budget close to 1×10^{-19} for a multi-ion clock operated with mixed In$^+$/Yb$^+$ crystals.

[1] J. Keller et al., *J. Appl. Phys.* **118**, 104501 (2015)

Q 71.2 Fri 10:45 K 2.013

^{24}Mg optical lattice clock — •Nandan Jha, Dominika Fim, Klaus Zipfel, Steffen Rühmann, Steffen Sauer, Waldemar Friesen-Piepenbrink, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Magnesium is a promising candidate for an optical lattice clock due to its low black body radiation sensitivity. In our previous measurements, the tunneling induced broadening for the bosonic ^{24}Mg in shallow lattices had limited the linewidth of the clock transition to kHz scale [1]. We have improved upon these measurements by increasing the intracavity optical lattice power to perform spectroscopy in a $50\,E_r$ deep lattice. Reduced tunneling along with improved detection efficiency further allowed us to operate at lower excitation fields to achieve a linewidth below 50 Hz. With the reduced linewidth, we have performed our first systematic shift measurements with an overall error budget in the 10^{-15} regime. The fiber link setup by the group of G. Grosche between IQ, Hannover and PTB, Braunschweig [2] allowed us to compare the Mg lattice clock against the frequency references at PTB. In this contribution, we discuss our systematic shift measurements, as well as our efforts towards further improving the line-Q factor of the clock transition.

[1] A. Kulosa et al., Phys. Rev. Lett. **115**, 240801 (2015).
[2] G. Grosche, Opt. Lett. **39**, 2545 (2014).

Q 71.3 Fri 11:00 K 2.013

An iodine frequency reference based on an ECDL at 1064 nm for a sounding rocket mission. — •Franz Balthasar Gutsch[1], Klaus Döringshoff[1], Vladimir Schkolnik[1,2], Markus Krutzik[1,2], Achim Peters[1,2], and Team JOKARUS[1,2,3,4,5] — [1]Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]ZARM, Uni Bremen — [4]Johannes Gutenberg-Universität Mainz — [5]Menlo Systems GmbH, Martinsried

Within the JOKARUS collaboration, we built a autonomously operating, active optical absolute frequency reference at 1064 nm based on molecular iodine that is scheduled for launch on a sounding rocket (TEXUS 54) in April 2018. Laser-based frequency references with high accuracy and stability are needed for space missions dedicated to precision tests of fundamental physics, Earth observation, navigation or gravitational wave astronomy. Frequency stabilization to the narrow, sub-MHz hyperfine transitions of the iodine R(56)32-0 line provides the means to fulfill the requirements of planned missions like LISA or NGGM. Our system relies on modulation transfer spectroscopy of iodine gas at 532 nm, using a frequency-doubled, micro-integrated, narrow-linewidth ECDL MOPA. In order to verify the lock stability, there will be an in-flight comparison to an RF-clock-referenced frequency comb. In this talk, we report on the system design, performance and results of environmental testing. Further, we present the auto-lock as well as our approach to experiment control. This work is supported by the DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM 1646.

Q 71.4 Fri 11:15 K 2.013

Characterisation of a Reference Cavity for a Transportable Sr Optical Clock. — •Sofia Herbers, Sebastian Häfner, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Ultra-stable high-finesse cavities are used, inter alia, in interrogation lasers of optical clocks, that are employed for relativistic geodesy or test of fundamental physics.

One limiting factor of ultra-stable high-finesse cavities is the Brownian noise of the mirror coatings. This noise is reduced for state-of-the-art cavities by using single-crystalline mirror coatings. Furthermore, the cavity needs to be isolated from environmental conditions like seismic noise or temperature fluctuations that result in a length change of the cavity. Therefore, special mounts have to be employed to decouple the cavity from seismic noise. However, for a transportable cavity, most of these approaches like a soft and loose mounting are not suitable. Thus, other solutions must be found that do not degrade the cavity performance.

Here, we present the characteristics of a transportable 20 cm long reference resonator for a transportable Sr lattice clock heading for a fractional frequency instability of $1 \cdot 10^{-16}$ using single-crystalline mirrors with a finesse up to 300 000 as well as a rigid cavity mounting.

This work is supported by QUEST and DFG (CRC 1128 (A03)). We thank Garrett Cole and colleagues from Crystalline Mirror Solutions (CMS) for supplying the crystalline coatings used in this work.

Q 71.5 Fri 11:30 K 2.013

Possibility of laser stabilization with trapped cavity-coupled ions — •Georgy Kazakov[1,2] and Thorsten Schumm[1] — [1]Technische Universität Wien — [2]Wolfgang Pauli Institut

The concept of an active optical frequency standards was proposed about 10 years ago [1,2]. The idea is to use optically trapped alkaline-earth atoms as a gain medium to built an extremely narrow-line laser, whose frequency will be robust to fluctuations of the cavity length. The main challenge towards the realization of this concept is the short trap lifetime of the atoms. Recently we showed [3], that in such a laser, neutral atoms may be replaced by charged ions in a radio-frequency Paul trap with much longer lifetime. Our idea is based on the effect of syncronization of radiating dipoles and on the possibility to compensate (in leading orders) micromotion-induced shifts for some ion species in specially designed traps. We discuss in detail the perspectives of creating of the bad cavity laser based on a Coulomb crystal in the linear Paul trap. We consider compensation of the micromotion-induced shifts, coupling of the quadrupole transition with the cavity mode in different geometries, various ion species and clock transitions as well as pumping schemes, and estimate attainable characteristics of different trapped-ion bad-cavity lasers.

[1] J. Chen, X. Chen, Proceedings of the 2005 IEEE Int. Freq. Cont. Symp. Exp. 608 (2005) [2] D. Meiser et al, Phys. Rev. Lett. 102, 163601 (2009) [3] G. Kazakov et al, Phys. Rev. A 96, 023412 (2017)

Q 71.6 Fri 11:45 K 2.013

QUEEN: Design Study for Optical Frequency References on Small Satellites — •Aline N. Dinkelaker[1], Heike Christopher[2], Doreen Brandt[2], Philipp Werner[3], Julian Bartholomäus[3], Merlin F. Barschke[3], and Markus Krutzik[1] — [1]Humboldt-Universität zu Berlin — [2]FBH Berlin — [3]TU Berlin

Optical frequency references are key to fundamental physics experiments involving cold atoms or optical atomic clocks. For future experiments in space, the frequency references have to be compact and robust in order to meet the size, weight and power (SWaP) requirements while providing the experiments with frequency stabilized light of sufficient optical output power. In the Phase 0/A study QUEEN, a mission for the demonstration of optical frequency references is investigated. Small satellites are ideally suited for in-orbit demonstration as they allow rapid, iterative mission development. For QUEEN, the modular, flight-proven TUBiX20 platform by TU Berlin will be adjusted to match the payload's requirements. We examine the use of a micro-integrated, frequency-stabilized semiconductor diode laser system by HU Berlin and FBH for in-orbit demonstration of an optical frequency reference and present possible mission scenarios. Long-term tests in orbit –specifically with respect to thermal variation and exposure to radiation– thus complement existing experiments in drop towers and on sounding rockets.

The QUEEN project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50 WM 1753-1755.

Q 71.7 Fri 12:00 K 2.013

Laser-induced electronic bridge for characterization of the ^{229m}Th isomer transition with a tunable optical laser — •Pavlo Bilous[1], Ekkehard Peik[2], and Adriana Pálffy[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

The isotope ^{229}Th is unique among the other nuclei due to its long-lived first excited state ^{229m}Th at the energy of 7.8 eV lying in the optical range. Its decay to the ground state has very narrow width and high stability to external fields, rendering ^{229}Th a candidate for a first nuclear clock at unprecedentedly high relative accuracy of 10^{-19}. Precise knowledge of the transition parameters such as energy and γ-decay rate is however needed for its implementation.

Due to the low energy of the state ^{229m}Th the nuclear transition can be strongly coupled to the atomic shell processes with considerable enhancement of the nuclear decay rate. An example of such processes is laser-induced electronic bridge (LIEB) [1]. The excited nuclear state decays by transfering its energy to the outer electrons. The electronic shell is then promoted to a high-lying bound state by absorption of a laser photon and a virtual photon coming from the nucleus. Here we investigate theoretically LIEB as a means for precise determination of the ^{229m}Th energy and γ-decay rate. Depending on the actual value of the nuclear transition energy, the enhancement factor compared to the radiative nuclear decay can achieve up to 10^8 [1].

[1] P. V, Bilous, E. Peik and A. Pálffy, New J. Phys. in press (2017)