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

Dagmar Bruß
Heinrich-Heine-Universität Düsseldorf
Universitätsstraße 1
40225 Düsseldorf
dagmar.bruss@uni-duesseldorf.de

Overview of Invited Talks and Sessions

(Lecture rooms P 2, 3, 4, 5, 11, 104, and 204; Poster P 1.OG)

Invited talks of the joint symposium SYDD

See SYDD for the full program of the symposium.

SYDD 1.1	Mon	14:30–15:00	P 1	**Controlling (?) Quantum Dynamics with Open Systems** — •Dieter Meschede
SYDD 1.2	Mon	15:00–15:30	P 1	**Many-body physics of driven, open quantum systems: optically driven Rydberg gases** — •Michael Fleischhauer
SYDD 1.3	Mon	15:30–16:00	P 1	**Theorie getriebener dissipativer Quantensysteme / theory of driven dissipative quantum systems** — •Tobias Brandes
SYDD 1.4	Mon	16:00–16:30	P 1	**Calorimetry of a Bose-Einstein-condensed photon gas** — •Martin Weitz

Invited talks of the joint symposium SYAP

See SYAP for the full program of the symposium.

SYAP 1.1	Tue	11:00–11:30	P 1	**Electrons and ions meet ultracold atoms** — •Herwig Ott
SYAP 1.2	Tue	11:30–12:00	P 1	**Interrogating strongly bound electrons about fundamental physics** — •José R. Creso López-Urrutia
SYAP 1.3	Tue	12:00–12:30	P 1	**Strong-field effects in heavy-ion collisions** — •Andrey Surzhykov, Vladimir Yerokhin, Thomas Stöhlker, Stephan Fritzsche
SYAP 1.4	Tue	12:30–13:00	P 1	**Laser-based high photon flux XUV sources and applications in atomic physics** — •Jan Rothhardt, Robert Klas, Stefan Demmler, Maxim Tschernajew, Jens Limpert, Andreas Tünnermann

Invited talks of the joint symposium SYAD

See SYAD for the full program of the symposium.

SYAD 1.1	Wed	11:00–11:30	RW 1	**Exciton transport in disordered organic systems** — •Franziska Fennel
SYAD 1.2	Wed	11:30–12:00	RW 1	**Quantum dynamics in strongly correlated one-dimensional Bose gases** — •Florian Meinert
SYAD 1.3	Wed	12:00–12:30	RW 1	**Dynamics and correlations of a Bose-Einstein condensate of light** — •Julian Schmitt
SYAD 1.4	Wed	12:30–13:00	RW 1	**Circular dichroism and accumulative polarimetry of chiral femtochemistry** — •Andreas Steinbacher

Invited talks of the joint symposium SYAM

See SYAM for the full program of the symposium.

SYAM 1.1	Thu	11:00–11:30	P 1	**Buffer gas cooling of antiprotonic helium to T=1.5-1.7 K, and the antiproton to electron mass ratio** — •Masaki Hori

SYAM 1.2	Thu	11:30–12:00	P 1	**The BASE Experiment: High-precision comparisons of the fundamental properties of protons and antiprotons** — •C. Smorra, M. Besirli, K. Blaum, M. Bohman, M. J. Borchert, J. Harrington, T. Higuchi, H. Nagahama, Y. Matsuda, A. Mooser, C. Ospelkaus, W. Quint, S. Sellner, G. Schneider, N. Schoen, T. Tanaka, J. Walz, Y. Yamazaki, S. Ulmer
SYAM 1.3	Thu	12:00–12:30	P 1	**Antihydrogen physics at the ALPHA experiment** — •Niels Madsen
SYAM 2.1	Thu	14:30–15:00	P 1	**Muon g-2** — •Klaus Jungmann
SYAM 2.2	Thu	15:00–15:30	P 1	**Antihydrogen physics at ASACUSA and AEGIS** — •Chloé Malbrunot
SYAM 2.3	Thu	15:30–16:00	P 1	**An experiment to measure the anti-hydrogen Lamb shift** — •Paolo Crivelli

Invited talks of the joint symposium SYLG

See SYLG for the full program of the symposium.

SYLG 1.1	Fri	11:00–11:30	P 1	**Quantum Simulation of Lattice Gauge Theories with Cold Atoms and Ions** — •Peter Zoller
SYLG 1.2	Fri	11:30–12:00	P 1	**Quantum Simulations with Cold Trapped Ions** — Esteban A. Martinez, Christine A. Muschik, Philipp Schindler, Daniel Nigg, Alexander Erhard, Markus Heyl, Philipp Hauke, Marcello Dalmonte, Thomas Monz, Peter Zoller, •Rainer Blatt
SYLG 1.3	Fri	12:00–12:30	P 1	**Studies of hot and dense nuclear matter at the Large Hadron Collider** — •Boleslaw Wyslouch
SYLG 1.4	Fri	12:30–13:00	P 1	**Lattice gauge theory beyond QCD** — •Claudio Pica

Sessions

Q 1.1–1.6	Mon	14:30–16:30	P 2	**Quantum Information: Concepts and Methods I**
Q 2.1–2.8	Mon	14:30–16:45	P 3	**Quantum Communication I**
Q 3.1–3.7	Mon	14:30–16:15	P 4	**Quantum Effects: QED I**
Q 4.1–4.6	Mon	14:30–16:15	P 5	**Quantum Optics I**
Q 5.1–5.7	Mon	14:30–16:30	P 104	**Precision Measurements and Metrology: Gravity**
Q 6.1–6.8	Mon	14:30–16:30	P 204	**Quantum Gases: Bosons I**
Q 7.1–7.7	Mon	14:30–16:30	N 1	**Ultracold atoms and BEC - I (with A)**
Q 8.1–8.8	Mon	17:00–19:00	P 2	**Quantum Information: Concepts and Methods II**
Q 9.1–9.8	Mon	17:00–19:00	P 3	**Quantum Communication II**
Q 10.1–10.6	Mon	17:00–18:30	P 4	**Quantum Effects: QED II**
Q 11.1–11.7	Mon	17:00–18:45	P 5	**Quantum Optics II**
Q 12.1–12.8	Mon	17:00–19:00	P 11	**Nano-Optics I**
Q 13.1–13.8	Mon	17:00–19:00	P 104	**Precision Measurements and Metrology: Optical Clocks**
Q 14.1–14.8	Mon	17:00–19:00	P 204	**Quantum Gases: Bosons II**
Q 15.1–15.8	Mon	17:00–19:00	N 1	**Ultracold atoms and BEC - II (with A)**
Q 16.1–16.7	Tue	11:00–12:45	P 2	**Quantum Information: Concepts and Methods III**
Q 17.1–17.8	Tue	11:00–13:00	P 3	**Quantum Repeater and Quantum Communication**
Q 18.1–18.7	Tue	11:00–12:45	P 4	**Quantum Effects: Cavity QED I**
Q 19.1–19.6	Tue	11:00–12:30	P 5	**Quantum Optics III**
Q 20.1–20.8	Tue	11:00–13:00	P 11	**Nano-Optics II**
Q 21.1–21.8	Tue	11:00–13:00	P 104	**Precision Measurements and Metrology: Interferometry I**
Q 22.1–22.8	Tue	11:00–13:00	P 204	**Quantum Gases: Bosons III**
Q 23.1–23.8	Tue	14:30–16:30	P 2	**Quantum Information: Concepts and Methods IV**
Q 24.1–24.6	Tue	14:30–16:15	P 3	**Quantum Information: Solid State Systems I**
Q 25.1–25.7	Tue	14:30–16:15	P 4	**Quantum Effects: Cavity QED II**
Q 26.1–26.6	Tue	14:30–16:00	P 5	**Quantum Optics IV**
Q 27.1–27.8	Tue	14:30–16:30	P 11	**Nano-Optics III**
Q 28.1–28.9	Tue	14:30–16:45	P 104	**Precision Measurements and Metrology: Interferometry II**
Q 29.1–29.9	Tue	14:30–16:45	P 204	**Quantum Gases: Bosons IV**
Q 30.1–30.8	Tue	14:30–16:30	N 1	**Ultracold atoms and BEC - III (with A)**
Q 31.1–31.94	Tue	17:00–19:00	P OGs	**Poster: Quantum Optics and Photonics I**
Q 32.1–32.7	Wed	14:30–16:15	P 2	**Quantum Information: Concepts and Methods V**

Q 33.1–33.7	Wed	14:30–16:15	P 3	**Quantum Information: Solid State Systems II**
Q 34.1–34.8	Wed	14:30–16:45	P 4	**Quantum Effects: Entanglement and Decoherence**
Q 35.1–35.8	Wed	14:30–16:30	P 5	**Laser Development and Applications (Spectroscopy)**
Q 36.1–36.8	Wed	14:30–16:45	P 11	**Photonics I**
Q 37.1–37.8	Wed	14:30–16:45	P 104	**Ultracold Plasmas and Rydberg Systems**
Q 38.1–38.9	Wed	14:30–16:45	P 204	**Quantum Gases: Bosons V**
Q 39.1–39.8	Wed	14:30–16:30	N 1	**Ultracold atoms and BEC - IV (with A)**
Q 40.1–40.66	Wed	17:00–19:00	P OGs	**Poster: Quantum Optics and Photonics II**
Q 41.1–41.7	Thu	11:00–13:00	P 2	**Quantum Information: Concepts and Methods VI**
Q 42.1–42.8	Thu	11:00–13:00	P 4	**Quantum Effects**
Q 43.1–43.4	Thu	11:00–12:15	P 5	**Laser Applications: Optical Measurement Technology**
Q 44.1–44.8	Thu	11:00–13:00	P 11	**Photonics II**
Q 45.1–45.8	Thu	11:00–13:15	P 104	**Ultracold Plasmas, Rydberg Systems and Molecules**
Q 46.1–46.7	Thu	11:00–13:00	P 204	**Quantum Gases: Fermions I**
Q 47.1–47.6	Thu	14:30–16:15	P 2	**Quantum Computing I**
Q 48.1–48.5	Thu	14:30–15:45	P 4	**Optomechanics I**
Q 49.1–49.9	Thu	14:30–16:45	P 5	**Ultrashort Laser Pulses: Generation and Applications**
Q 50.1–50.6	Thu	14:30–16:00	P 11	**Matter Wave Optics**
Q 51.1–51.7	Thu	14:30–16:30	P 104	**Ultracold Atoms I**
Q 52.1–52.9	Thu	14:30–16:45	P 204	**Quantum Gases: Fermions II**
Q 53.1–53.86	Thu	17:00–19:00	P OGs	**Poster: Quantum Optics and Photonics III**
Q 54.1–54.8	Fri	11:00–13:00	N 1	**Ultracold atoms and BEC - V (with A)**
Q 55.1–55.7	Fri	14:30–16:15	P 2	**Quantum Computing II**
Q 56.1–56.5	Fri	14:30–15:45	P 4	**Optomechanics II**
Q 57.1–57.8	Fri	14:30–16:30	P 104	**Ultracold Atoms II**
Q 58.1–58.8	Fri	14:30–16:30	P 204	**Quantum Gases: Fermions III**
Q 59.1–59.5	Fri	14:30–16:00	N 1	**Ultracold atoms and BEC - VI (with A)**

Annual General Meeting of the Quantum Optics and Photonics Division

Tuesday 13:15–14:00 P 2

Q 1: Quantum Information: Concepts and Methods I

Time: Monday 14:30–16:30 Location: P 2

Group Report Q 1.1 Mon 14:30 P 2
Control of quantum state transfer in one dimensional structures — •David Petrosyan — Institute of Electronic Structure & Laser, Foundation for Research and Technology - Hellas, Heraklion, Crete, Greece

After an outline of the activities of our theoretical Quantum Optics and Technology group, which involve studies of cold atoms, coherent quantum effects in atomic ensembles, interacting Rydberg gases, physical implementations of quantum computation and communication, and quantum cryptography, I will present some of our results on control and manipulation of quantum state transfer in several physical settings, including atomic and photonic lattices.

Faithful transfer of quantum states in spin chains is indispensable for scalable realization of quantum computation in many systems where qubit-qubit interactions have finite range. I will discuss state transfer protocols in spin chains with static and dynamic inter-spin couplings, and their robustness with respect to diagonal and off-diagonal disorder. I will then present a scheme for a quantum spin transistor in a Heisenberg spin chain, which realizes conditional state transfer. A proof-of-concept realization of the device can be done with just a few cold, trapped atoms, but the idea is generally applicable to various other implementations of spin chains. Finally, I will describe manipulation and transfer of non-classical motional states of atoms in a lattice using Rydberg dressing with off-resonant lasers.

Group Report Q 1.2 Mon 15:00 P 2
Toward the Limits of Controlling Closed and Open Quantum Systems — •Thomas Schulte-Herbrüggen[1], Ville Bergholm[1,2], Frank K. Wilhelm[3], and Gunther Dirr[4] — [1]Technical University of Munich (TUM) — [2]University of Helsinki — [3]University of Saarbrücken — [4]University of Würzburg

Optimal control is proving more and more indispensable for steering quantum devices with high fidelity. Recent examples in NV centres include single-shot readout quantum sensing enhanced via a quantum memory [1].

Here we report on latest extensions of the optimal-control platform DYNAMO [2]. They include switchable noise as additional control beyond coherent ones and its implications for reachability under open-loop versus closed-loop control designs.

We propose experimental implementation of fast noise switching in a superconducting device, i.e. a two-qutrit GMon with fast tunable coupling to an open transmission line serving as a low-temperature bath. The setting is closest to the one available in the Martinis group.

References:
[1] S. Zaiser et al., Nature Commun. 7, 12279 (2016).
[2] S. Machnes et al., Phys. Rev. A 84, 022305 (2011).
[3] V. Bergholm, F.K. Wilhelm, and T. Schulte-Herbrüggen, arXiv:1605.06473

Q 1.3 Mon 15:30 P 2
Quantum control of few level systems — Marcus Theisen[1] and •Sandro Wimberger[1,2,3] — [1]ITP, Heidelberg University, 69120 Heidelberg, Germany — [2]DiFeST, Università degli Studi di Parma, 43124 Parma, Italy — [3]INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, Italy

We present and discuss possible ways to exert quantum control on few level systems. The focus is on finding protocols that drive the system's dynamics exactly. These protocols describe the temporal developement of control parameters, e.g., external fields in spin resonance experiments. In particular, we are interested in superadiabatic protocols (1) which allow for adiabatic population transfer between quantum states. This type of transitionless quantum driving is illustrated for the Landau-Zener model. Similar control protocols are tested for more complex 2 and 3 level systems numerically. They are found to result in the desired behaviour. Future prospects include possible ways to stir the 4 level quantum system as a basic model for two interacting Qbits. All protocols could turn out to be useful in quantum computation.

(1) M. V. Berry, Transitionless quantum driving, J. Phys. A, 42 (365303), 2009

Q 1.4 Mon 15:45 P 2
Randomized Benchmarking with symmetries — •Emilio Onorati[1], Albert H. Werner[2], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany — [2]Department of Mathematical Sciences, University of Copenhagen, Denmark

A central step toward the realization of quantum information processing devices is the estimation of the accuracy in the implementation of unitary gates. While a complete characterization of any quantum operation may be obtained through quantum process tomography, this approach suffers from two major shortcomings: SPAM errors sensitivity and exponentially growing necessary resources. Randomized benchmarking has become a standard technique to overcome these limitations. The method involves the measurement of density operators after application of a random sequence of gates, chosen from the Clifford or other small groups, which drastically reduces the number of needed parameters. While randomized benchmarking has proven to be successful in numerous experiments, the initial assumptions of the protocol are demanding: up to small perturbations, the average error is assumed to be both gate- and time-independent with respect to all gates. We propose a novel approach to overcome these issues: by exploiting the symmetries of the gates to be benchmarked, we are able to estimate the error of each operator individually. To this aim, knowledge regarding the representation theory of the symmetry group is necessary; nevertheless, we investigate how well-known and small groups allow for the characterization of a large number of multi-qubit gates.

Q 1.5 Mon 16:00 P 2
Limits of Quantum Control: bounds on minimum time and control field amplitudes — •Christian Arenz, Benjamin Russell, and Herschel Rabitz — Frick Laboratory, Princeton University, Princeton NJ, 08544 US

We derive a lower bound for the time that is needed in order to implement a target unitary transformation through classical time-dependent fields. The bound depends on the target gate, the strength of the internal Hamiltonian and the highest control field amplitude. Furthermore, based on the established bound we characterize the reachable set of unitary operations as a function of the evolution time and the control field amplitude, here explicitly analyzed for a single qubit. Moreover, for a fully controllable system we show that the derived bound yields a lower bound for the time at which all unitary gates become reachable. We use numerical gate optimization in order to study the tightness of the obtained bounds. It is shown that in the single qubit case our analytical findings describe remarkably well the limit of reducing the highest control field amplitude and the evolution time as much as possible, while still being able to implement some unitary target operation. Finally we discuss the challenges in obtaining more accurate bounds for higher dimensional systems.

Q 1.6 Mon 16:15 P 2
Recovering the ideal results of a perturbed analog quantum simulator — •Iris Schwenk[1], Jan-Michael Reiner[1], Sebastian Zanker[1], Lin Tian[2], Juha Leppäkangas[1], and Michael Marthaler[1] — [1]Institute of Theoretical Solid State Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]School of Natural Sciences, University of California, Merced, California 95343, USA

Well controlled quantum systems can potentially be used as quantum simulators. However inevitably a quantum simulator is perturbed by coupling to additional degrees of freedom. This constitutes a major roadblock to useful quantum simulations, since so far there are only a limited amount of possibilities to understand the effects of these perturbation on the result of the quantum simulation. We present a method which in limited circumstances, allows for the reconstruction of the ideal result from measurements on a perturbed quantum simulator. We study the case where we are interested in extracting a correlator $\langle \hat{O}^i(t)\hat{O}^j(0)\rangle$ from the simulated system in equilibrium, where $\hat{O}^i$ are the operators which couple the system to its environment. The ideal correlator can be reconstructed if any n-time correlator of operators $\hat{O}^i$ of the ideal system can be written as products of two-time correlators. We give an approach to verify the validity of this assumption experimentally using additional measurements on the perturbed quantum simulator.

Q 2: Quantum Communication I

Time: Monday 14:30–16:45 Location: P 3

Group Report Q 2.1 Mon 14:30 P 3

Event-ready Bell test using entangled atoms simultaneously closing detection and locality loopholes — •Wenjamin Rosenfeld[1,2], Daniel Burchardt[1], Kai Redeker[1], Robert Garthoff[1], Norbert Ortegel[1], Markus Rau[1], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Bell's inequality allows testing experimentally whether nature can be described in a local-realistic way. In order for such a test to be meaningful, at least two major requirements need to be fulfilled: the detection efficiency of the particles has to be high enough and the measurements on the two sides have to be space-like separated in order to avoid loopholes. It is due to these demanding requirements, that it took more than 40 years of experimental development until such tests became possible.

Here we present our results for a Bell test using heralded entanglement of two neutral Rb-atoms over a distance of 400 m [1]. The obtained violation of $2.22 \pm 0.033 > 2$ provides a strong evidence against local realism. Beyond their fundamental importance such tests also form the basis for novel communication methods like device-independent quantum key distribution. Moreover, entanglement of remote quantum memories is a central building block of future quantum repeaters.

[1] arXiv:1611.04604 [quant-ph]

Q 2.2 Mon 15:00 P 3

Large-Alphabet Quantum Key Distribution Using Spatially Encoded Light — •Tristan Tentrup, Willemijn Luiten, Peter Hooijschuur, Reinier van der Meer, and Pepijn Pinkse — University of Twente, Enschede, The Netherlands

In order to transmit a secret message between a sender (Alice) and a receiver (Bob), both parties need a shared secret for encryption and decryption. Quantum Key Distribution (QKD) provides a secure way of generating such shared keys. The original BB84 protocol uses a two-dimensional polarization basis, limiting the information content of a single photon to 1 bit. Using the position of single photons as one basis and the Fourier space as second basis, one can construct a pair of mutually unbiased higher-dimensional bases. This improves not only the security of the protocol, but also the key generation rate. We present our experimental results with an encoding scheme using a Spatial Light Modulator (SLM) allowing two nearly orthogonal alphabets with in the order of 10^3 symbols and an information content per single photon of about 10 bit.

Q 2.3 Mon 15:15 P 3

Time-Frequency Quantum Key Distribution Over Free Space — •Fabian Beutel[1,2], Jasper Rödiger[1,2], Nicolas Perlot[1], Ronald Freund[1], and Oliver Benson[2] — [1]Fraunhofer Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany — [2]Humboldt-Universität zu Berlin, AG Nanooptik, Newtonstraße 15, 12489 Berlin, Germany

Quantum key distribution (QKD) enables the creation of a common secret key between two remote parties that are connected by a quantum channel. In the time-frequency (TF)-QKD scheme, Alice encodes her bits either in the arrival time (Pulse Position Modulation) or in the center frequency (Frequency Shift Keying) of weak laser pulses. Due to the time-frequency uncertainty relation, an eavesdropper can only extract limited information from intercepting these pulses. As with the traditional BB84 QKD scheme, post processing allows for the distillation of a secret key.

We have successfully implemented the TF-QKD scheme by using mostly off-the-shelf telecom components and avalanche photodiodes operating at 1550 nm. With our setup we achieve secret-key rates of more than 400 kbit/s back-to-back and 80 kbit/s over a 25 km fiber spool. Furthermore, we have tested our scheme over an outdoor free-space test range of 390 m in the Berlin city center and are currently in the process of extending it to longer outdoor test ranges.

Q 2.4 Mon 15:30 P 3

A Compact Quantum Key Distribution Sender Module for Handheld Operation — Gwenaelle Mélen[1], Tobias Vogl[2], Peter Freiwang[2], •Jannik Luhn[2], Clemens Sonnleitner[2], Wenjamin Rosenfeld[2], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Ludwig-Maximilians-Universität, Munich, Germany

Quantum Key Distribution (QKD) over free space channels offers a multitude of different application scenarios – provided it can be combined with conventional communication systems. Employing micro-optics and waveguide circuits enables a new level of integration. Here we present a novel miniaturized sender module ready for handheld operation in combination with a tracking receiver.

Our system implements a BB84-like protocol. A visible beacon laser allows aiming and is modulated for synchronization purposes. A classical communication channel between sender and receiver is established by means of a smartphone via Wi-Fi. We will report on results demonstrating secure key rates on the order of a few 100 kBit/s in mounted and a few 10 kBit/s in handheld operation at quantum bit error ratios (QBERs) of less than 2%.

Our concept should enable QKD sender optics no larger than a single match. With this size and robustness it is well suited for a huge variety of communication schemes. It can be integrated in mobile phones or optical wireless systems, but also be combined with classical communication links, e.g., free-space optical systems in urban areas or even micro-satellites thereby enabling global key exchange.

Q 2.5 Mon 15:45 P 3

Photon-photon to atom-photon entanglement transfer — •Stephan Kucera, Jan Arenskötter, Pascal Eich, Matthias Kreis, Philipp Müller, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Implementation of a quantum network with single atoms as quantum nodes and single photons as channels between the nodes requires their interfacing in receiver mode, whereby the photonic qubit is mapped onto the internal degrees of freedom of the atom [1]. Combining such a receiver interface with a source of entangled photon pairs enables the distribution of entanglement between network nodes.

We implemented the heralded state-mapping protocol of [2] to operate a single trapped $^{40}Ca^{+}$ ion in receiver mode. Using a high-brightness narrowband source of resonant entangled photon pairs, we transferred the photon-photon polarization entanglement to atom-photon entanglement by heralded absorption of one photon of the pair. Quantum state tomography on the polarization qubit of the other photon of the pair and the atomic spin qubit after absorption demonstrates the preservation of the entanglement.

[1] Kurz et al., Phys. Rev. A **93**, 062348 (2016).
[2] Kurz et al., Nat. Commun. **5**, 5527 (2014).

Q 2.6 Mon 16:00 P 3

Spectral properties of single photons from a single Ca^+ ion — •Philipp Müller, Tristan Tentrup, Marc Bienert, Jürgen Eschner, and Giovanna Morigi — Universität des Saarlandes, Experimentalphysik, Campus E 2.6, Saarbrücken

Pure photonic quantum states, such as Fourier-limited single photons, are optimal qubit carriers to attain high bandwidth in quantum communication. They are generated, for example, from a single trapped ion in a Raman-scattering process [1, 2]. The same process allows heralded single-photon absorption [3].

We developed a method, based on resolvent theory and the residue theorem, to calculate the spectro-temporal properties of the Raman-emitted photon for incident light of arbitrary spectrum and for excitation by coherent light or by single photons. We particularly include the branching ratio of the three-level system.

Application to the experimental situation of a trapped single Ca^+ ion allows us to control the atom–photon interaction, optimise the photon-generation efficiency, and generate single photons with tailored properties.

[1] Almendros et al., Phys. Rev. Lett. **103**, 213601 (2009).
[2] Kurz et al., New J. Phys. **15**, 055005 (2013).
[3] Kurz et al., Phys. Rev. A **93**, 62348 (2016).

Q 2.7 Mon 16:15 P 3

Polarization-entangled photon pairs from a cavity-enhanced down-conversion source in Sagnac configuration — •Jan Arenskötter, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

An efficient resource of entanglement in atom–photon-based quantum networks are polarization-entangled photon pairs generated by type-II spontaneous parametric down-conversion.

Up to date, the best entanglement values are achieved by single-pass conversion in Sagnac configuration [1]. On the other hand, the highest pair rates are reported in cavity-enhanced sources [2]. We combine the two approaches and generate frequency-degenerate photon pairs at 854 nm wavelength in a signal- and idler-resonant bow-tie resonator with 10 MHz linewidth, tuned to resonance with the $D_{5/2} \leftrightarrow P_{3/2}$ transition in the $^{40}Ca^+$ ion. We achieve a brightness of $5.4 \cdot 10^3$ $(\mathrm{s\,MHz\,mW})^{-1}$ fiber-coupled pairs with up to 97 % fidelity (at 20 mW pump power) to a maximally entangled state, whose phase is fully adjustable between Ψ^+ and Ψ^-. This source will be employed in quantum communication experiments [3].

[1] Kuzucu et al., Phys. Rev. A **77**, 032314 (2008).
[2] Luo et al., New J. Phys. **17** 073039 (2015).
[3] Kurz et al., Phys. Rev. A **93**, 62348 (2016).

Q 2.8 Mon 16:30 P 3

Conversion of single photons from a trapped ^{40}Ca$^+$-ion to the telecom range — •Pascal Eich, Matthias Bock, Matthias Kreis, Stephan Kucera, Jan Arenskötter, Christoph Becher, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

A key ingredient for quantum networks is the controlled generation and distribution of photons as carriers of quantum information, in order to establish the communication between atomic network nodes. For long-range communication, the need for quantum frequency conversion of such photons from atomic wavelengths into the low-fiber-loss telecom range arises.

We generate triggered, polarization-controlled single photons at 854 nm on the $P_{3/2} \leftrightarrow D_{5/2}$ transition of a single trapped $^{40}Ca^+$-ion, and investigate their conversion to the telecom O-band at 1312 nm via difference-frequency generation in a nonlinear waveguide. We study the single-photon character as well as the polarization of the photons before and after the conversion process.

Q 3: Quantum Effects: QED I

Time: Monday 14:30–16:15 Location: P 4

Q 3.1 Mon 14:30 P 4

Casimir effect for perfect non-reciprocal conductors: An analytic extension of Casimir's original work — •Stefan Rode, Robert Bennett, and Stefan Yoshi Buhmann — Albert-Ludwigs University of Freiburg, Germany

We present the Casimir effect for boundary conditions involving perfect electromagnetic conductors (PEMCs), which are a class of non-reciprocal materials that interpolate between perfectly electrically conducting and perfect magnetically conducting media. Based on the dyadic Green's tensor of the electromagnetic field between two reciprocal plates, we demonstrate the construction of the corresponding quantity for two perfectly reflecting non-reciprocal plates. We then calculate the Casimir force between two PEMC plates in terms of the parameter that specifies the degree of mixing between electric and magnetic responses. Our results are simple analytic expressions, which can be related to the electric-magnetic duality symmetry of the electromagnetic field.

Q 3.2 Mon 14:45 P 4

Casimir forces in media: comparison of microscopic and macroscopic descriptions — •Friedrich Burger, Johannes Fiedler, and Stefan Yoshi Buhmann — Institute of Physics, University of Freiburg, Germany

We consider the Casimir force between two dielectric bodies in a medium, motivated by a recent debate initiated by Raabe and Welsch [1]: the Casimir force as an effective electromagnetic force on a dieletric object due to a second object can be expressed as a surface integral over a stress tensor. Two alternative choices, the Maxwell stress tensor [1] on the one hand and the Abraham-Minkowski stress tensor [2] on the other, then lead to different results when the objects are embedded in a medium. We analyse a setup of two dielectric spheres within a medium [3] and present a comparison of both approaches with the result obtained from microscopic Hamaker theory [4].

[1] C. Raabe and D.-G. Welsch, Phys. Rev. A **71**, 013814 (2005).
[2] I. Dzyaloshinskii, E. M. Lifshitz and L. P. Pitaevskii, Adv. Phys. **10** 165 (1961).
[3] A. Sambale, S. Y. Buhmann and S. Scheel, Phys. Rev. A **81**, 012509 (2010).
[4] H. C. Hamaker, Physica **4**, 1058 (1937).

Q 3.3 Mon 15:00 P 4

Dispersion forces in inhomogenous media — •Johannes Fiedler[1], Priyadarshini Thiyam[2], Mathias Boström[2], Michael Walter[1,3], and Stefan Yoshi Buhmann[1] — [1]Institute of Physics, University of Freiburg, Germany — [2]Department of Materials Science and Engineering, Royal Institute of Technology, Sweden — [3]Fraunhofer Institute for Mechanics of Materials, Germany

Dispersion forces, such as Casimir forces between dielectric bodies and van der Waals forces between neutral particles, are a consequence of the ground-state fluctuations of the electromagnetic field [1]. In modern precision experiments and theories, these forces are usually studied in vacuum [2]. However, typical realistic systems arising in nature, e.g. in biological contexts, often involve particles embedded in liquid solvent media. The latter can strongly modify the van der Waals interaction. Due to the Pauli blocking the solvent forms a void, or real cavity, around the particles [3], which has to be taken into account when studying the van der Waals interaction. We investigate the influence of such a solvent on the dispersion force for a quasi one-dimensional model cases of two plates of finite thickness and infinite lateral extension on the one hand and two atoms on the other. We model the real cavity by a realistic density profile of the solvent near the interacting objects and compare our results with those obtained from a simpler hard-cavity model with step-function profile.

[1] S.Y. Buhmann, Dispersion forces I, Springer (Heidelberg, Berlin) 2012. [2] S. K. Lamoreaux, Phys. Rev. Lett. **78**, 5 (1997). [3] A. Held, M. Walter, J. Chem. Phys. **141**, 174108 (2014).

Q 3.4 Mon 15:15 P 4

Relevance of non-equilibrium effects for dispersion forces — •Francesco Intravaia — Max-Born-Institut, 12489 Berlin, Germany

Non-equilibrium systems are omnipresent and in recent years they have attracted a constantly growing attention due to their relevance for fundamental physics as well as for modern nanotechnology. Progress in manipulating atomic and condensed matter systems has stimulated the investigation of a particular class of non-equilibrium phenomena, which is represented by dynamical dispersion forces. These forces, whose origin is deeply rooted in quantum theory, are at the origin of contactless quantum friction between two objects moving with constant velocity relative to each other. Unfortunately, the detailed quantitative description of non-equilibrium systems is rather challenging and the most common approaches rely on the assumption that corrections to the associated equilibrium characteristics are relatively small. We show that this assumption fails for quantum friction and underestimates by approximately 80% the magnitude of the drag force [1]. Our results show that the correlations among the components of driven but steady-state quantum systems invalidate the so-called local thermal equilibrium approximation, also calling for a critical reexamination of this approach for describing the physics of non-equilibrium systems.

[1] F. Intravaia, R. O. Behunin, C. Henkel, K. Busch, and D. A. R. Dalvit, Failure of local thermal equilibrium in quantum friction, Phys. Rev. Lett. 117, 100402 (2016).

Q 3.5 Mon 15:30 P 4

Casimir-Polder Interaction across Timescales — •Juliane Klatt and Stefan Yoshi Buhmann — Physikalisches Institut, Albert-Ludwigs-Universität, Freiburg

Casimir-Polder interaction is the fluctuation-mediated interplay between a neutral but polarizable microscopic object, e.g. an atom, on the one hand and a macroscopic body on the other. For an atom at rest, the three most common approaches to describing such interaction

- perturbation theory, Markovian master equations and linear response theory - yield compatible results. For an atom moving relative to the macroscopic body, however, the predictions of these three methods strongly disagree.

This discrepancy can be attributed to incompatible assumptions regarding the power spectra as implied by the aforementioned approaches, which in turn is a manifestation of the mutually exclusive temporal regimes to which the seemingly contradicting results apply. The different Casimir-Polder dynamics in these temporal regimes can be understood in analogy to the observation that the spontaneous decay of an excited atom in free space undergoes three, qualitatively distinct, phases - Gaussian decay, exponential decay and powerlaw decay - each of which can be reproduced by the corresponding method, i.e. perturbation theory, Markovian master equations and linear response, respectively.

We here employ time-convolutionless projection operator techniques in order to develop a comprehensive description of Casimir-Polder interaction across all timescales.

Q 3.6 Mon 15:45 P 4

Casimir-Polder Potential for an Atom driven by a Laser Field — •Sebastian Fuchs, Robert Bennett, and Stefan Buhmann — Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Within the framework of Macroscopic QED we study the interaction between an atom driven by a coherent laser field with a surface and compute the Casimir-Polder potential. We use two different ideas to approach this goal. If the atom is not driven resonantly and remains in its initial state, we can split the dipole moment into a free contribution coming from spontaneous polarization according to Macroscopic QED, and the induced part given by a polarizability and the driving field. The total Casimir-Polder potential also consists of the standard Casimir-Polder part, the induced potential. We contrast this to a resonantly driven atom showing Rabi oscillations between its excited state and the ground state. In a next step we seek to extend this model to a larger number of atoms and investigate the collective behavior using Dicke states.

Q 3.7 Mon 16:00 P 4

Dynamical Casimir effect in a spinor BEC — •Karsten Lange[1], Jan Peise[1], Bernd Lücke[1], Ilka Kruse[1], Frank Deuretzbacher[2], Luis Santos[2], Wolfgang Ertmer[1], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Theoretische Physik, Leibniz Universität Hannover

One of the most surprising predictions of quantum theory is the generation of particles out of the vacuum by suddenly changing the boundary conditions. This effect is known as the dynamical Casimir effect. Originally, it was proposed for mirrors that move at relativistic speeds. We realize an analogous effect in our ^{87}Rb spinor BEC by changing the the energy of initially empty spin modes. Firstly, we demonstrate the creation of spin excitations in these vacuum states. Secondly, we employ atomic homodyning to prove that the created excitations are entangled.

Q 4: Quantum Optics I

Time: Monday 14:30–16:15 Location: P 5

Group Report Q 4.1 Mon 14:30 P 5

A mixed bag of quantumness with a bit of tech — Kai Barnscheidt, Tom Ettrich, •Boris Hage, Semjon Köhnke, Melanie Mraz, Christian Reiher, Dieter Schick, and Oskar Schlettwein — Universität Rostock, Institut für Physik, AG Experimentelle Quantenoptik, Rostock, Germany

We report on the activities of the research group 'Experimental Quantumoptics' at the University of Rostock, which are divided into three areas:

1) The detection and verification including experimental errors of the quantumness/nonclassicality of the state of a laser beam using linear, nonlinear and single photon detectors. Additionally, the advance towards a measurement based quantification of nonclassicality.

2) The complete quantum state tomography (single mode) of a pulsed multi mode squeezed state of light emerging from a Kerr nonlinear optical fibre. Additionally, the advances towards a reliable simulation of the processes in the optical fibre including losses, dispersion (higher order), Kerr nonlinearity and Raman effect.

3) Progress towards the implementation of an optical spring with micro cantilevers used in atomic force microscopy with an optical excitation using photothermal and radiation pressure coupling.

Q 4.2 Mon 15:00 P 5

Phase-insensive test of phase-squeezed state nonclassicality — •Melanie Mraz[1], Benjamin Kühn[2], Semjon Köhnke[1], Werner Vogel[2], and Boris Hage[1] — [1]AG Experimentelle Quantenoptik, Institut für Physik, Universität Rostock — [2]AG Theoretische Quantenoptik, Institut für Physik, Universität Rostock

We experimentally realized the homodyne cross correlation detection (HCCD) proposed in [1]. This technique is based on an intensity noise correlation. Three different normally ordered moments of field amplitude and intensity are extracted from the recorded correlation in two dissimilar ways; by phase periodicity and by order of the local oscillator strength. We used a coherently displaced phase-squeezed state at 1064 nm with approx. -2.7dB squeezing generated in an optical parametric amplifier (OPA). To verify the presented method and to analyze the amount of squeezing, we used a standard balanced homodyne detector (BHD). The special features of our HCCD are an unbalanced splitting ratio of 14:86 and a matched local oscillator (LO) power to the order of magnitude of the signal power. This delivers us the needed information of three different normal ordered moments of field amplitude and intensity. A nonclassicality criterion is developed which is solely based on these moments. Remarkably, this test certifies quantum correlations for all phases, i.e., even in the antisqueezed region, of the generated squeezed state. Furthermore, the analysis of the data is free of quantum physical assumptions as present in the standard balanced homodyne detection.

[1] W. Vogel, Phys. Rev. A 51, 4160 (1995).

Q 4.3 Mon 15:15 P 5

Experimental Demonstration of Negative-Valued Polarization Quasi-Probability Distribution — •Kirill Spasibko[1,2], Maria Chekhova[2,3,1], and Farid Khalili[3] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7/B2, 91058 Erlangen, Germany — [2]Max-Planck-Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [3]Faculty of Physics, M. V. Lomonosov Moscow State University, 119991 Moscow, Russia

The polarization analog of the position-momentum Wigner distribution is the polarization quasi-probability distribution (PQPD) for the three non-commuting Stokes observables. This distribution fully describes the polarization properties of a quantum state and gives correct one-dimensional marginal probability distributions for all Stokes observables and their linear combinations (as the Wigner distribution for position and momentum does).

Usually the negativity of the Wigner distribution is considered as a proof of non-classicality for a quantum state. On the contrary, the PQPD demonstrates negativity for all quantum states. This feature comes from the discrete nature of the Stokes observables.

In this work [arXiv:1508.03510] we have demonstrated the experimental reconstruction of the PQPD for a linearly-polarized weak coherent state of light measured with single-photon detectors. The reconstructed distribution demonstrates well pronounced negative-valued areas. This intrinsic negativity was not observed in previous experiments, because they were performed with photon-number averaging detectors.

Q 4.4 Mon 15:30 P 5

Overcoming Vacuum Noise: The Unforeseen Benefits of Quantum Heterodyne Detection — •Christian R. Müller[1,2], Christian Peuntinger[1,2,3], Thomas Dirmeir[1,2], Imran Khan[1,2], Ulrich Vogl[1,2], Christoph Marquradt[1,2], Gerd Leuchs[1,2], Luis L. Sánchez-Soto[4,1], Yong S. Teo[5], Zdenek Hradil[5], and Jaroslav Rehacek[5] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Germany. — [3]Department of Physics, University of Otago, New Zealand. — [4]Departamento de Óptica, Facultad de Física, Universidad Complutense, Madrid, Spain. — [5]Department of Optics, Palacky University, Olomouc, Czech Republic.

The Wigner function and the Husimi Q-function are theoretically equivalent representations of a quantum state and are intimately linked to homodyne tomography and heterodyne detection, respectively. In state estimation via these measurement techniques one is confronted either with errors incurred during tomogram processing or with additional excess noise due to the simultaneous measurement of conjugate observables. We experimentally demonstrate that, contrary to a common believe, state estimation via heterodyne detection outperforms homodyne tomography for almost all Gaussian states.

[1] J. Řeháček et al., Sci. Rep., 5, 12289 (2015).
[2] C. R. Müller et al., Phys. Rev. Lett. 117, 070801 (2016)

Q 4.5 Mon 15:45 P 5

Quantum state tomography of Kerr squeezed femto second pulses in optical fibers — •Oskar Schlettwein, Kai Barnscheidt, and Boris Hage — Institut für Physik, Universität Rostock, Germany

The intensity dependence of the refractive index in standard optical fibers is usually very small ($n_2 \sim 10^{-20} \frac{m^2}{W}$). However it still can get a significant impact if short pulses with high peak power are launched into the small mode field diameter of the fiber. Using 250 fs (FWHM) pulses with peak power in the kW regime the impact of the appearing Kerr- and Raman-effect on the quantum properties of the light field are experimentally analyzed. For this purpose a new schema based on a ring cavity is set up to perform a full quantum state tomography of the light field.

Since the fiber output pulses are multimode quantum states the choice of the local oscillator (LO) plays a crucial role in the tomography. Our setup can be used to gain a LO which has the same temporal pulse shape as our signal without any further shaping technics needed. This allows us to also analyze the quantum properties of non-soliton pulses.

With the further addition of a pulse shaper in the LO path the multimode quantum structure of the Kerr squeezed pulses could be experimentally investigated. Our nummerical calculations predict separable squeezed modes in the pulse with a high amount of squeezing. The shape of this modes as well as the progress into their experimental investigation will be demonstrated.

Q 4.6 Mon 16:00 P 5

A Kalman Filter Approach to Quantum State Reconstruction — •Karsten Bölts, Stefan Scheel, and Boris Hage — Institut für Physik, Universität Rostock, Albert-Einstein-Str. 23-24, 18059 Rostock, Deutschland

Kalman filtering, a technique which is mostly used for dynamical state estimation in the field of engineering, can also be applied to quantum state reconstruction [1]. This method yields not only the optimal Bayesian state estimate but also treats the measurement uncertainties properly and can in principle be adapted to any tomographic set-up. The reconstruction scheme is mainly based on linear vector equations and hence it is well suited for hardware implementation.

Here we show how to apply the Kalman filter method to balanced homodyne tomography [2]. We implemented a version of the algorithm on a field programmable gate array (FPGA) to enable hardware-assisted real-time state reconstruction and calculation of error bars.

[1] K. M. R. Audenaert and S. Scheel, *New J. Phys.* **11**, 023028 (2009)
[2] E. Agudelo, J. Sperling, W. Vogel, S. Köhnke, M. Mraz and B. Hage, *Phys. Rev. A* **92**, 033837 (2015)

Q 5: Precision Measurements and Metrology: Gravity

Time: Monday 14:30–16:30 Location: P 104

Group Report Q 5.1 Mon 14:30 P 104

The Laser Ranging Interferometer on GRACE Follow-On - current status and outlook — Germán Fernández Barranco, Alexander Görth, •Christoph Mahrdt, Vitali Müller, Daniel Schütze, Gunnar Stede, Gerhard Heinzel und Karsten Danzmann — Albert-Einstein-Institut (AEI), Hannover

The Gravity Recovery and Climate Experiment (GRACE) is able to observe the Earth's dynamic gravitational field on a global scale. Changes due to mass transport within the Hydrosphere and Cryosphere, with unprecedented precision have been observed with a temporal resolution of one month. Long term monitoring of these changes is important for a better understanding of the processes causing these time variations. GRACE has been flying for nearly 15 years now, tripling it's targeted design lifetime. Due to the increasing risk of failure a rebuild of GRACE has been build and is currently under test for an anticipated launch as early as spring 2018. GRACE Follow-On carries an additional laser ranging interferometer as technology demonstrator for future gravity field missions which has the potential to enable improved spatial resolution. This talk will give an overview of the architecture of the laser ranging interferometer, a status update, and outlook towards the launch.

Q 5.2 Mon 15:00 P 104

Precise measurement of pW laser powers for inter-satellite laser interferometry applications — •Sebastian Schreiber, Alexander Görth, Christoph Vorndamme, Nils Christopher Brause, Oliver Gerberding, Thomas Schwarze, Gerhard Heinzel, and Karsten Danzmann — Albert-Einstein-Institut Leibniz Universität Hannover

Future space missions like the Laser Interferometer Space Antenna (LISA) or the Gravity Recovery and Climate Experiment Follow-on mission (GRACE-FO) will make use of laser interferometry to measure precise distance changes between the spacecraft.

The huge distances between the SC reduce the received laser power to a few nW or even pW. To ease the alignment procedure of the SC an acquisition sensor will be installed on each SC.

To ensure the correct functionality of those sensors it is necessary to measure such light intensities on ground. Noise sources such as residual, scattered or reflected light as well as electronic readout noise are actually limiting the achievable results from common instruments.

This talk will present a general overview and first ideas of building a measuring instrument which is able to directly measure such low intensities. The focus lies on AC measurement techniques that involve optical chopper wheels or heterodyne interferometey

Q 5.3 Mon 15:15 P 104

Deep Frequency Modulation Interferometry — •Christoph Vorndamme[1], Oliver Gerberding[2], Katharina-Sophie Isleif[1], Thomas S. Schwarze[1], Moritz Mehmet[2], Gerhard Heinzel[2], and Karsten Danzmann[1,2] — [1]Albert Einstein Institute, Leibniz Universität Hannover — [2]Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Here we present the latest developments for the deep frequency modulation interferometry (DFMI) technique at the AEI. This technique is based on a Michelson setup with unequal armlength and a strong, or deep, frequency modulation applied to the input laser. The unequal armlength converts the laser frequency modulation into an effective deep phase modulation in the measurement arm, thus encoding the measurement phase in complex amplitudes of the modulation frequency harmonics. Unlike in a phase modulated setup, which already provides high precision and high dynamic range, the frequency modulated setup can be implemented with very compact optical heads for a scalable amount of degrees of freedom. This is due to the laser frequency modulation and reference noise measurement being kept seperate from the part of the optics that need high thermal and mechanical stability. Futhermore, the effective modulation depth includes the total delay in the measurement arm, thus yielding the possibility for absolute ranging. The presented efforts include the construction of optical hardware like a glued ultra-stable reference interferometer as well as the developement of fast phase readout electronics (phasemeter) based on a system on chip (SoC).

Q 5.4 Mon 15:30 P 104

Interferometrischer Messkopf zur dynamischen Laser-Entfernungsmessung — •Oliver Mandel[1,2], Thilo Schuldt[2,3], Michael Chwalla[1], Dennis Weise[1], Ulrich Johann[1] und Claus Braxmaier[2,3] — [1]Airbus DS GmbH, Friedrichshafen — [2]Zentrum

für angewandte Raumfahrttechnologie und Mikrogravitation (ZARM), Bremen — [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bremen

Die Laserinterferometrie gilt in der Raumfahrt als vielversprechende Technologie zur dynamischen Abstandsmessung zwischen Satelliten, besonders im Hinblick auf Missionen zur Erdbeobachtung, Detektion von Gravitationswellen und Formationsflügen. Verschiedene Konzepte für ein heterodynes, dynamisches Laser-Entfernungsmessgerät mit Nanometergenauigkeit wurden auf ihre Nutzbarkeit für Gravitations-Missionen der nächsten Generation untersucht und hinsichtlich ihrer Messgenauigkeit, Baugröße, Flexibilität und Komplexität verglichen. Darauf aufbauend wird ein monostatisches Instrumentendesign vorgestellt, bei dem sich die Laserstrahlen auf der direkten Sichtverbindung zwischen den Satelliten ausbreiten, wobei innerhalb des Instruments eine bi-statische Strahlführung Anwendung findet. Die tatsächliche Leistungsfähigkeit soll in einer eigens dafür entwickelten Testumgebung vermessen werden. Zur leichteren Unterbringung in zukünftigen Satellitenmissionen ermöglicht das Instrumentendesign einen frei wählbaren Abstand vom Messkopf zum Phasenzentrum und kann vollständig auf einer kompakten optischen Bank integriert werden. Zuwendung des DLR mit Mitteln des BMWi unter dem Förderkennzeichen 50EE1409.

Q 5.5 Mon 15:45 P 104

A backlink for LISA: Pre-experiment and optical design — •Lea Bischof[1], Katharina-Sophie Isleif[1], Oliver Gerberding[2], Daniel Penkert[2], Stefan Ast[2], Gerhard Heinzel[2], Michael Winter[1], Jens Reiche[2], and Karsten Danzmann[1,2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover — [2]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut)

The Laser Interferometer Space Antenna (LISA) is a planned space-based gravitational wave detector with arm-lengths of several million kilometers. To suppress laser frequency noise in this detector two or more arms have to be compared to synthesize a quasi Michelson interferometer. This is non-trivial due to an orbit induced breathing of the angle between the arms, which requires an adaptable link (so-called backlink) between two optical benches in one satellite. Therefore, a new experiment is currently being set-up at the AEI in Hannover to compare three different methods: a 'fiber backlink', a 'free beam backlink' and a 'frequency separated backlink'. All bonded on two baseplates that are fixed on two rotary stages to simulate a LISA like motion. We will present the current status of this, so called '3Backlink-experiment', the stray light mitigation strategies and the actual implementation of a pre-experiment that will analyze key issues for the free beam backlink. Highlights include first results with a free beam backlink, including angular steering control, and the IfoCAD based design of the highly complex three backlink interferometer.

Q 5.6 Mon 16:00 P 104

Experiment to investigate collinear back-reflections of optical components — •Michael Winter[1], Oliver Gerberding[2], Katharina-Sophie Isleif[1], Daniel Penkert[2], Stefan Ast[2], Lea Bischof[1], Gerhard Heinzel[2], Jens Reiche[2], and Karsten Danzmann[1,2] — [1]Albert Einstein Institute Hannover, Leibniz Universität Hannover — [2]Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

The Laser Interferometer Space Antenna (LISA) is a planned space-based gravitational wave detector with arm lengths of some million kilometres. Due to orbital dynamics the angle between the arms changes. Thus an adaptable link (backlink) between the two optical benches inside each spacecraft is required. Previous experiments have shown that a fiber solution is limited by collinear ghost beams. Additional optical components can be used to avoid them or make them irrelevant, e.g. Faraday Isolators or AOMs. Collinear back-reflections of the components are designated to be the new limiting factors.

To investigate these back-reflections a simple cavity-like setup is used, whereby the component to be examined forms one half of an ultra-low finesse cavity. Deep Frequency Modulation (DFM) interferometry is then applied to generate self-interference at AC-frequencies for a quasi heterodyne detection.

This talk will give an overview of the operating principle and the characterization of the setup. Thereby the focus lies on reconciling theory and experiment to connect obtained signal and power reflectivity of the device-under-test, revealing collinear back-reflection properties.

Q 5.7 Mon 16:15 P 104

Optical three-signal test for the LISA phasemeter — •Germán Fernández Barranco, Daniel Penkert, Thomas Schwarze, Oliver Gerberding, and Gerhard Heinzel — Max Planck Institute for Gravitational Physics, Callinstraße 38 30167 Hannover

The planned spaceborne gravitational wave detector LISA will allow the detection of gravitational waves at frequencies between 0.1 mHz and 1 Hz. It uses high-precision heterodyne laser interferometry as the main measurement technology. A breadboard model of the interferometric phase readout system (phasemeter) was developed in the scope of an ESA technology development project. This project was completed successfully fulfilling all performance requirements in an electrical two-signal test. Here we present the advances of an optical testbed for the phasemeter as well as measurements. The testbed is based on an ultra-stable hexagonal optical bench. This bench allows the generation of three unequal heterodyne beatnotes, thus enabling us to probe the phasemeter for nonlinearities in an optical three-signal test. The final goal is to show a performance in the microcycle/sqrt(Hz) regime for the upper part of the LISA measurement band (5 mHz to 1 Hz) with a dynamic range of about 7 orders of magnitude using beatnotes between 5 and 25 MHz. The measurements presented here fulfill this requirement down to 100 mHz including dynamic and beatnote ranges. Once full performane is achieved, other components of the LISA arm metrology chain (clock noise transfer and removal, inter-satellite ranging and communication) can be tested in this setup.

Q 6: Quantum Gases: Bosons I

Time: Monday 14:30–16:30 Location: P 204

Q 6.1 Mon 14:30 P 204

The Space Atom Laser - A novel 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

The atom laser [1] is a unique device among the broad variety of applications of Bose-Einstein condensation (BEC) and transfers magnetically trapped atoms to an untrapped state. On ground the outcoupled atoms are dragged down by gravity resulting in an accelerated, directed beam. In microgravity, however, there is no favored direction and the only driving force of the dynamics is the repulsive interaction between the particles. Thus, the outcoupled atoms propagate away from the remaining trapped atoms and form a slowly expanding shell.

We present a 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 find a suitable scheme for an experimental implementation aboard the ISS using NASAs Cold Atom Laboratory we have thoroughly studied this process with the help of numerical simulations based on coupled Gross-Pitaevskii equations.

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.

[1] Phys. Rev. Lett. **78**, 582 (1997); Science **283**, 1706 (1999); Phys. Rev. Lett. **82**, 3008 (1999);

Q 6.2 Mon 14:45 P 204

Lowest-Lying Collective Frequencies of a Photon BEC in Presence of Temporally Retarded Interaction — •Enrico Stein and Axel Pelster — Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

Usually, collective mode frequencies of BECs are theoretically described for an instantaneous two-particle interaction between the bosons. Recent experiments on photon BECs show, however, that the effective photon-photon interaction is significantly influenced by memory effects which are presumably due to diffusion processes [1,2]. Therefore, we analyse the lowest-lying collective modes of a two-dimensional BEC in presence of a temporally retarded interaction by solving the underlying Gross-Pitaevskii equation with a variational approach [3]. We find that the frequencies for both the breathing and the quadrupole mode are shifted for a few percent with respect to a non-retarded two-particle interaction. Furthermore, we find the same order of magnitude for the violation of the Kohn theorem [4], i.e. the dipole-mode frequency differs from the trap frequency. Finally, we discuss how these retardation effects can be enhanced in an anisotropic harmonic confinement. All these findings are essential for determining the photon-photon interaction strength from measuring the lowest-lying collective frequencies of the photon BEC.

[1] J. Klaers, et al., Appl. Phys. B **105**, 17 (2011)
[2] J. Schmitt, et al., Phys. Rev. A **92**, 011602(R) (2015)
[3] V.M. Perés-Garciá, et al., Phys. Rev. Lett. **77**, 5320 (1996)
[4] A.L. Fetter and D. Rokhsar, Phys. Rev. A **57**, 1191 (1998)

Q 6.3 Mon 15:00 P 204

Strongly anomalous non-thermal fixed point in a quenched two-dimensional Bose gas — •Markus Karl[1,2] and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Universal scaling behaviour in the relaxation dynamics of an isolated two-dimensional Bose gas is studied by means of semi-classical stochastic simulations of the Gross-Pitaevskii model. The system is quenched far out of equilibrium by imprinting vortex defects into an otherwise phase-coherent condensate. A strongly anomalous non-thermal fixed point is identified, signalled by a universal scaling form for the time-dependent occupation spectrum at late times. The fixed point is associated with a slowed power-law decay of the defects in the case that the dissipative coupling to the thermal background noise is suppressed. Interpreting our results in the context of phase-ordering kinetics and coarsening dynamics, we find numerical evidence for a new type of defect-ordering process far from equilibrium. This process is characterised by a large dynamical critical exponent $z = 5$, implying an anomalously slow algebraic progress of the system towards thermal equilibrium, and is distinctly different from coarsening within known near-equilibrium universality classes.

Q 6.4 Mon 15:15 P 204

Driven Bose-Hubbard Model with a Parametrically Modulated Harmonic Trap — Niklas Mann[1], •M. Reza Bakhtiari[1], Francesco Massel[2], Axel Pelster[3], and Michael Thorwart[1,4] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Germany — [2]Department of Physics and Nanoscience Center, University of Jyväkylä, Finland — [3]Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany — [4]The Hamburg Centre for Ultrafast Imaging, Germany

We investigate a periodically driven one-dimensional Bose-Hubbard model, where the global harmonic trap is parametrically modulated. The delicate interplay of both the local atom interaction and the global driving allows to control the dynamical stability of the trapped quantum many-body state. This mechanism is illustrated for weak atom interaction by solving the discretized version of the Gross-Pitaevskii equation within a Gaussian variational ansatz, yielding to a Mathieu equation for the condensate width. With this it turns out that the parametric resonance condition can be tuned with the atom interaction strength. For stronger interactions, this mechanism is confirmed by applying the numerically exact time-evolving block decimation scheme. Furthermore, we show that the global periodic modulation induces for large enough driving frequencies an effective time-independent local hopping strength for the atom gas.

Q 6.5 Mon 15:30 P 204

Continuous and discontinuous dark solitons in polariton condensates — •Stavros Komineas[1,2], Stephen Shipman[3], and Stephanos Venakides[4] — [1]University of Crete, Heraklion, Crete, Greece — [2]RWTH Aachen University, 52056, Aachen, Germany — [3]Louisiana State University, Baton Rouge, Louisiana 70803, USA — [4]Duke University, Durham, North Carolina 27708, USA

Bose-Einstein condensates of exciton-polaritons are described by a Schroedinger system of two equations for the wavefunctions of the excitons and the photons. The system is nonlinear due to exciton interactions. We have calculated all non-traveling soliton solutions for the one-dimensional lossless system. We will present in detail the frequency bands of dark soliton solutions. For positive detuning (photon frequency higher than exciton frequency), there is a frequency band for which the exciton wavefunction becomes discontinuous when the operating frequency exceeds the exciton frequency. The exciton wavefunction is discontinuous at its symmetry point, where it undergoes a phase jump of pi. A band of ordinary (continuous) dark solitons merges with the band of discontinuous dark solitons, forming a larger band over which the soliton far-field amplitude varies from 0 to infinity.

This phenomenon lies outside the parameter regime of validity of the Gross-Pitaevskii (GP) model. Within its regime of validity, we give a derivation of a single-mode GP model from the initial Schroedinger system and compare the continuous polariton solitons and GP solitons using the healing length notion.

Q 6.6 Mon 15:45 P 204

Measuring the Edwards-Anderson parameter in a disordered Bose-Hubbard model — •Antonio Rubio-Abadal[1], Jae-yoon Choi[1], Johannes Zeiher[1], Simon Hollerith[1], Sebastian Hild[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, Germany

Quantum gas microscopes provide exciting perspectives to study disordered systems, since short-range-correlated disorder potentials can be generated, and microscopic observables probed with single-site resolution. A recent theory study [1] points out that such a setup could be used to probe the disordered Bose-Hubbard (BH) model by measuring an analogue of the Edwards-Anderson (EA) parameter, a commonly adopted "order parameter" in the context of spin glasses. Here we report on the direct measurement of the analogue EA parameter in disordered BH systems. We find a non-vanishing value in between the Mott lobes, indicating the presence of a Bose glass. These regions grow with disorder strength as expected. Our measurements provide a chemical-potential-resolved characterization of the phase diagram of the disordered BH model.

[1] S.J. Thomson et al. Phys. Rev. A 94, 051601(R) (2016)

Q 6.7 Mon 16:00 P 204

Realization of a Bose-Hubbard model with cavity-mediated global-range interactions — •Nishant Dogra[1], Renate Landig[2], Lorenz Hruby[1], Katrin Kröger[1], Manuele Landini[1], Rafael Mottl[1], Ferdinand Brennecke[3], Sebastian Huber[4], Tobias Donner[1], and Tilman Esslinger[1] — [1]HPF D4, Quantum Optics Group, Institute for Quantum Electronics, ETH Zurich,Otto-Stern-Weg-1,Zurich-8093 — [2]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [3]Physikalisches Institut, Universität Bonn, Wegelerstrasse 8, Bonn-53115 — [4]HIT K 23.4, Institute for Theoretical Physics, ETH Zurich, Wolfgang-Pauli-Strasse 27, Zurich-8093

We experimentally realize a lattice model with cavity-mediated global-range interactions using a Bose-Einstein condensate (BEC). The global-range interactions are created by coupling the BEC to a single mode of a high-finesse cavity and illuminating it with a transverse laser-field. Their strength can be controlled by tuning the relative frequency of the transverse laser and the cavity. The presence of three competing energy scales- tunnelling, short-range interactions and global-range interactions gives rise to a rich phase diagram. We observe four different phases- a superfluid, a supersolid, a Mott insulator and a charge density wave. We also theoretically investigate the various features of our system within a mean-field framework which provides more insight about the nature of transitions between different phases.

Q 6.8 Mon 16:15 P 204

Observation of Four-body Ring-exchange Interaction and Anyonic Fractional Statistics — •Han-Ning Dai[1,2,3], Bing Yang[1,2,3], Andreas Reingruber[2,5], Hui Sun[1,3], Xiao-Fan Xu[2], Yu-Ao Chen[1,3,4], Zhen-Sheng Yuan[1,2,3,4], and Jian-Wei Pan[1,2,3,4] — [1]Hefei National Laboratory for Physical Science at Microscal and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [2]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [3]CAS Center for Excellence and Synergetic Innovation Center in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui, 230026, China — [4]CAS-Alibaba Quantum Computing Laboratory, Shanghai 201315, China — [5]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schroedinger-Strasse, Building 46, 67663 Kaiserslautern, Germany

We report the observation of four-body ring-exchange interactions and the topological properties of anyonic excitations within an ultracold atom system. A minimum toric code Hamiltonian in which the ring exchange is the dominant term, was implemented by engineering a Hubbard Hamiltonian that describes atomic spins in disconnected plaquette arrays formed by two orthogonal superlattices.

Q 7: Ultracold atoms and BEC - I (with A)

Time: Monday 14:30–16:30 Location: N 1

Invited Talk Q 7.1 Mon 14:30 N 1

Towards Atomtronic Interferometry — •Wolf von Klitzing — Institute of Electronic Structure and Laser, FORTH, 71110 Heraklion, Crete, Greece

Atom interferometers are some of the most sensitive instruments available to date. In order to avoid unwanted perturbations, most of the matterwave interferometers use atoms in free fall. This is largely due to the lack of appropriatly coherent matterwave guides. Here, we present a novel Sagnac interferometer based on state-dependent manipulation of atoms in waveguides using time-averaged adiabatic potentials (TAAP) [1,2]. In this clock-type matterwave interferometer the atoms are in different internal states in the two arms of the interferometer and can thus be manipulated nearly independently. In analogy to the magic frequency of the strontium lattice clocks, by carefully tuning the confining potential a magic-field strength can be found such that the linear dependence on the potential vanishes [3].

We will report the use of adiabatic potentials in the creation of ultra-bright atom lasers. And present initial experimental results towards the realization of this interferometer. Most notably the state-dependent manipulation and guiding of the atoms.

[1] P. Navez et al. N.J.Phys. **18**:7 075014 (2016)
[2] I. Lesanovsky and W. von Klitzing PRL **99**:8 083001 (2007)
[3] P. Treutlein et al. PRL **92**:20 203005 (2004)

Q 7.2 Mon 15:00 N 1

Towards coherent beam splitting in a TAAP ring atom waveguide — •Hector Mas[1,2], Saurabh Pandey[2,3], Giannis Drougakis[2,3], Patrick Navez[1], Konstantinos Poulios[2], Georgios Vasilakis[2], Thomas Fernholz[4], and Wolf von Klitzing[2] — [1]Department of Physics, University of Crete, Heraklion 70113, Greece — [2]IESL-FORTH, Heraklion 70013, Greece — [3]Department of Materials, Science and Technology, University of Crete, Heraklion 70113 — [4]School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom

Trapped atom interferometers are promising candidates for improving the sensitivity of cold atom based sensing devices by means of increasing the interaction time and decreasing the size of the devices. We present progress towards a Sagnac clock type interferometer employing the two hyperfine states (F=1 and F=2) of Rubidium 87 (Rb87) in a state-dependent time averaged adiabatic potential (TAAP) ring shaped waveguide. We report on experimental advances leading to the implementation of the full interferometric sequence with a focus on achieving coherent splitting, guiding and recombination of the atomic cloud inside the waveguide. A number of decoherence processes may arise during the interferometric cycle, e.g. fluctuations in the magnetic fields or rf/microwave excitation. We will introduce and discuss preliminary measurements on both the ring waveguide characterisation and the spectroscopy of cold atoms in TAAP potentials, focusing on the search for a magic frequency that will allow for much improved coherence times.

Q 7.3 Mon 15:15 N 1

QUANTUS-2 - Ultra Low Expansion Atomic Source for Matter Wave Interferometry in Extended Free Fall — •Peter Stromberger[1], Alexander Grote[1], Andre Wenzlawski[1], Patrick Windpassinger[1], and the QUANTUS-Team[1,2,3,4,5,6,7] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz — [2]Institut für Physik, Humboldt-Universität zu Berlin — [3]Ferdinand-Braun-Institut, Leibniz Institut für Höchstfrequenztechnik Berlin — [4]Institut für Quantenoptik, Leibniz-Universität Hannover — [5]ZARM, Universität Bremen — [6]Institut für Quantenphysik, Universität Ulm — [7]Institut für angewandte Physik, TU Darmstadt

QUANTUS-2 is a mobile high-flux rubidium BEC source used for experiments under microgravity in the drop tower in Bremen. To further decrease the expansion rate of the BEC, magnetic lensing - also known as delta-kick cooling - is crucial for observations after long evolution times in the range of seconds. Long evolution times are desirable, because the sensitivity of atom interferometers enhances quadratically with the interrogation time. Here we present our results of a lens, which leads to an observability of the BEC of up to 2.7 s after free expansion. This expansion rate is equivalent to an expansion rate of a thermal ensemble with a temperature below 100 pK in all three dimensions.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economic Affairs and Energy under grant numbers DLR 50 WM 1552-1557.

Q 7.4 Mon 15:30 N 1

Selfbound quantum droplets — •Matthias Wenzel, Matthias Schmitt, Fabian Böttcher, Carl Bühner, Igor Ferrier-Barbut, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Self-bound many-body systems are formed through a balance of attractive and repulsive forces and occur in many physical scenarios. Liquid droplets are an example of a self-bound system, formed by a balance of the mutual attractive and repulsive forces that derive from different components of the inter-particle potential. On the basis of the recent finding that an unstable bosonic dipolar gas can be stabilized by a repulsive many-body term, it was predicted that three-dimensional self-bound quantum droplets of magnetic atoms should exist.

Here we report on the observation of such droplets, with densities 10^8 times lower than a helium droplet, in a trap-free levitation field. We find that this dilute magnetic quantum liquid requires a minimum, critical number of atoms, below which the liquid evaporates into an expanding gas as a result of the quantum pressure of the individual constituents. Consequently, around this critical atom number we observe an interaction-driven phase transition between a gas and a self-bound liquid in the quantum degenerate regime with ultracold atoms.

Q 7.5 Mon 15:45 N 1

Quantum droplets in one-dimensional dipolar Bose-Einstein condensates — •Daniel Edler, Falk Wächtler, and Luis Santos — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

Recent experiments on dipolar Bose-Einstein condensates have reported the formation, due to quantum fluctuations, of a novel form of ultra-dilute stable droplets. We will show that in one-dimensional geometries these fluctuations lead to peculiar momentum dependence of the dipole-dipole interactions inducing an anomalous density dependence of the beyond-mean-field corrections. Further we will discussion the density distribution for different system parameters and the behaviour for included three-body losses.

Q 7.6 Mon 16:00 N 1

Purity oscillations in coupled Bose-Einstein condensates — •Jonathan Stysch, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

We investigate the many-body dynamics of two three-mode Bose-Einstein condensates (BECs) forming a six-mode system. Both three-mode subsystems are initially prepared as isolated, fully coherent BECs and are then rendered open systems by coupling them together. The dynamics induced by this coupling leads to a periodic loss and restoration of the coherence in each subsystem which is quantified by the purity of the single-particle density matrices of the respective subsystems. We show that these purity oscillations correspond with oscillations in the average contrast in interference experiments and are therefore linked to a quantity accessible in experiment.

Q 7.7 Mon 16:15 N 1

Dynamical Instabilities in Trapped Bose-Einstein Conden-

sates — •Torsten Victor Zache[1], Valentin Kasper[2], and Jürgen Berges[1] — [1]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg — [2]Physics Department, Harvard University, Cambridge MA 02138, USA

We study the nonlinear phenomenon of secondary instabilities (secondaries), which was proposed in the context of inflationary particle production, with ultracold atom systems. Specifically, we consider a one-dimensional two-component Bose gas that can be realized in different experimental setups and show analytically that it exhibits a primary instability characterized by exponentially growing occupation numbers of certain momentum modes. The primary instability is triggered by initial quantum fluctuations and leads to an amplified occupation of primarily stable modes at later times. We demonstrate the existence of these secondary instabilities in trapped Bose-Einstein condensates numerically employing the classical-statistical approximation. The process underlying the generation of secondaries can be identified with a nonlinear loop correction, which leads to an interpretation in terms of Feynman diagrams and allows us to analytically estimate the secondary growth rates to be integer multiples of the primary one.

Q 8: Quantum Information: Concepts and Methods II

Time: Monday 17:00–19:00 Location: P 2

Q 8.1 Mon 17:00 P 2

Theory-independent conclusions from bipartite quantum correlations — •Matthias Kleinmann[1], Tamás Vértesi[2], and Adán Cabello[3] — [1]University of the Basque Country UPV/EHU, Bilbao, Spain — [2]Hungarian Academy of Sciences, Debrecen, Hungary — [3]University of Sevilla, Sevilla, Spain

Bell-inequalities enable us to test quantum theory against a particular class of alternative theories, the local hidden variable models. Recent experiments have thoroughly ruled out these models. In the same spirit we investigate a different set of nonsignaling theories, in which measurements of many outcomes are constructed by selecting from two-outcome measurements. We derive tight inequalities for this set of theories and show that experiments using current quantum technology can demonstrate a violation of these inequalities. This makes it possible to perform tests of the structure of measurements, independent of the underlying theory. Our method also generalizes to other traits of quantum theory and as an example we present a theory-independent test of the compatibility structure occurring in quantum theory.

Q 8.2 Mon 17:15 P 2

Indistinguishability of causal relations from limited marginals — Costantino Budroni[1], •Nikolai Miklin[1], and Rafael Chaves[2] — [1]Universität Siegen, Walter-Flex-Str. 3 , 57068 Siegen, Germany — [2]International Institute of Physics, 59070 - 405 Natal, Brazil

Deciding global properties of a given object from partial information is a problem often encountered in the most diverse fields. In probability theory this problem is known as the marginal problem: deciding whether a given set of marginal probability distributions for some random variables arises from a joint distribution of all these variables. Another important problem is of a causal inference which arises in many cases together with the marginal problem. This problem questions whether observed correlations are compatible with some underlined causal structure.

We investigate the possibility of distinguishing among different causal relations starting from a limited set of marginals. Our main tool is the notion of adhesivity, that is, the extension of probability or entropies defined only on subsets of variables, which provides additional independence constraints among them. Our results provide a criterion for recognizing which causal structures are indistinguishable when only limited marginal information is accessible. Furthermore, the existence of such extensions greatly simplifies the characterization of a marginal scenario, a result that facilitates the derivation of Bell inequalities both in the probabilistic and entropic frameworks, and the identification of marginal scenarios where classical, quantum, and postquantum probabilities coincide.

Q 8.3 Mon 17:30 P 2

Entropic nonsignaling correlations — •Costantino Budroni[1] and Rafael Chaves[2] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]International Institute of Physics, Universidade Federal do Rio Grande do Norte, 59070-405 Natal-RN, Brazil

We introduce the concept of entropic nonsignaling correlations, i.e., entropies arising from probabilistic theories that are compatible with the fact that we cannot transmit information instantaneously. We characterize and show the relevance of these entropic correlations in a variety of different scenarios, ranging from typical Bell experiments to more refined descriptions such as bilocality and information causality. In particular, we apply the framework to derive the first entropic inequality testing genuine tripartite nonlocality in quantum systems of arbitrary dimension and also prove the first known monogamy relation for entropic Bell inequalities. Further, within the context of complex Bell networks, we show that entropic nonlocal correlations can be activated.

Q 8.4 Mon 17:45 P 2

Steering Criteria Based on Tsallis Entropies — •Ana Cristina Sprotte Costa, Roope Uola, Costantino Budroni, and Otfried Gühne — Universität Siegen, Siegen, Germany

Steering is a term coined by Schrödinger in 1935, within the context of the Einstein-Podolsky-Rosen argument to name Alice's ability in affecting Bob's state through her choice of a measurement basis. Steering has been formalized in terms of a quantum information task involving bipartite states and measurement settings, in which case the existence of entanglement is necessary but not sufficient. Steering inequalities based on entropic uncertainty relations have also been proposed and experimentally tested in the last years. Based on Tsallis entropies, we present a generalization for the entropic steering and its connection with known results from the literature. Special attention will be given for certain families of Tsallis entropies, in order to show that the violation of these generalized steering entropic criteria characterize also the presence of entanglement for bipartite quantum states.

Q 8.5 Mon 18:00 P 2

On weak values, eigenvalues and expectation values — •Jan Dziewior[1,2], Alon Ben-Israel[3], Lukas Knips[1,2], Mira Weissl[1,2], Ran Ber[3], Jasmin Meinecke[1,2], Christian Schwemmer[1,2], Lev Vaidman[3], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Departement für Physik, Ludwig-Maximilians-Universität, 80797 München, Germany — [3]Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Tel-Aviv 69978, Israel

Weak values, which have been introduced in 1988 by Aharonov, Albert and Vaidman, to this day constitute a controversial element in the debate about the foundations of quantum mechanics. While the usefulness of weak values has been demonstrated in various experimental applications, considerable disagreement prevails about their physical meaning.

Here we study the effects of the interaction between quantum systems and a pointer system in order to measure and evaluate their properties. Both in a theoretical analysis of the concept and in an experiment a fundamental difference between expectation values and weak values becomes apparent. Rather than having the statistical properties of expectation values, the similarity of the weak value to eigenvalues indicates that it is a definite property of pre- and post-selected quantum systems.

Q 8.6 Mon 18:15 P 2

Symmetries of multi-partite quantum systems — Markus Grassl[1] and •Robert Zeier[2] — [1]Max-Planck-Institut für die Physik des Lichts, Staudtstraße 2, 91058 Erlangen, Germany — [2]Department Chemie, Technische Universität München, Lichtenbergstraße 4, 85747 Garching, Germany

Multi-partite quantum systems exhibit an intricate structure not explained by properties of their subsystems alone. We study the plethora of emerging symmetries that are invariant under local operations. We enumerate these symmetries by computing Hilbert series and also explore connections to so-called Kronecker coefficients. We particularly focus on the case of three-qubit mixed states. Our work provides the foundation for a better understanding of non-local quantum states.

Q 8.7 Mon 18:30 P 2

Quantum Source-Channel Codes — •Fernando Pastawski, Henrik Wilming, and Jens Eisert — Freie Universität Berlin

Approximate quantum error-correcting codes are codes with "soft recovery guarantees" wherein information can be approximately recovered. In this article, we propose a complementary "soft code-spaces" wherein a weighted prior distribution is assumed over the possible logical input states. The performance for protecting information from noise is then evaluated in terms of entanglement fidelity. We apply a recent construction for approximate recovery maps, which come with a guaranteed lower-bounds on the decoding performance. These lower bound are straightforwardly obtained by evaluating entropies on marginals of the mixed state which represents the "soft code-space". As an example, we consider thermal states of the transverse field Ising model at criticality and provide numerical evidence that the entanglement fidelity admits non-trivial recoverability from local errors. This provides the first concrete interpretation of a bonafide conformal field theory as a quantum error-correcting code. We further suggest, that quantum source-channel codes could provide a framework to interpret the information structure of holography.

Q 8.8 Mon 18:45 P 2

Code properties from holographic geometries — •Fernando Pastawski[1] and John Preskill[2] — [1]Freie Universität Berlin — [2]California Institute of Technology

Almheiri, Dong, and Harlow proposed a highly illuminating connection between the AdS/CFT holographic correspondence and operator algebra quantum error correction (OAQEC). Here we explore this connection further. We derive some general results about OAQEC, as well as results that apply specifically to quantum codes which admit a holographic interpretation. We introduce a new quantity called price, which characterizes the support of a protected logical system, and find constraints on the price and the distance for logical subalgebras of quantum codes. We show that holographic codes defined on bulk manifolds with asymptotically negative curvature exhibit uberholography, meaning that a bulk logical algebra can be supported on a boundary region with a fractal structure. We argue that, for holographic codes defined on bulk manifolds with asymptotically flat or positive curvature, the boundary physics must be highly nonlocal, an observation with potential implications for black holes and for quantum gravity in AdS space at distance scales small compared to the AdS curvature radius.

Q 9: Quantum Communication II

Time: Monday 17:00–19:00 Location: P 3

Q 9.1 Mon 17:00 P 3

A single ion coupled to UV fiber cavity — •Pascal Kobel[1], Timothy Ballance[1], Kilian Kluge[1], Konstantin Ott[2], Hendrik M. Meyer[1], Jakob Reichel[2], and Michael Köhl[1] — [1]Physikalisches Institut, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany — [2]Laboratoire Kastler-Brossel, ENS/UPMC-Paris 6/CNRS, F-75005 Paris, France

We investigate the integration of fiber cavities into ion traps for use in quantum networks.

Up to now, fiber-cavities have been combined with trapped ions only in the infra-red spectral range. Since ions typically have their strongest dipole transition in the ultra-violet (UV), the extension of fiber cavities to work in the UV is important.

We present coupling of a single Ytterbium ion to a 150 μm long fiber-cavity, which is resonant with the electric dipole transition at 370 nm. We achieve a coherent coupling rate of a single ion to the cavity of about $g/2\pi = 60$ MHz, which exceeds previous realizations by more than one order of magnitude. Using the Purcell effect, we demonstrate single photon generation by continuous and pulsed ion excitation and investigate correlation between the photon polarization and the spin state of the ion.

Q 9.2 Mon 17:15 P 3

Controlled absorption of a single photon — •Luigi Giannelli[1], Tom Schmit[1], Susanne Blum[1,4], Daniel M. Reich[2,3], Christiane P. Koch[2], Tommaso Calarco[5], and Giovanna Morigi[1] — [1]Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Universität Kassel, 34132 Kassel, Germany — [3]Aarhus University, 8000 Aarhus C, Denmark — [4]Theodor-Heuss-Gymnasium, 73730 Esslingen am Neckar, Germany — [5]Universität Ulm, 89069 Ulm, Germany

We numerically analyse the dynamics of a single photon propagating in free space and incident on the mirror of an optical cavity, in which an atom is localized. Our purpose is to identify the parameter regimes and dynamics which allow for perfect absorption of the photon by the atom. The cavity is modeled by a single mode, while the relevant electronic states of the atom form a three-level Lambda 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 $\Omega(t)$, whose temporal behaviour is optimized for the purpose of controlling absorption. We consider dissipative processes and compare the efficiency of adiabatic protocols, such as in [1-3], with the ones which employ optimal control in order to speed up the process. We also discuss the quantum speed limit of this process.

[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 9.3 Mon 17:30 P 3

Low temperature spectroscopy of Germanium vacancy center — •Mathias H. Metsch[1], Lachlan J. Rogers[1], Aroosa Ijaz[2], Jan M. Binder[1], Petr Siyushev[1], and Fedor Fedor[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Germany — [2]Institute of Quantum Electronics, ETH Zurich, CH-8093 Zurich

The negatively-charged Germanium vacancy (GeV) center in diamond has recently attracted interest as a quantum emitter. Systems offering a spin degree of freedom and efficient optical access are highly sought after in the quantum information processing context. Currently known color centers in diamond offer either good spin properties (Nitrogen vacancy) or good optical properties (Silicon vacancy). The GeV center in diamond has similar chemical structure to the SiV. In this talk the spectroscopy of single GeV is presented, highlighting outstanding spectral stability and brightness. Its brightness indicates a high quantum yield, making GeV even more appealing as a light matter interface than Silicon vacancy. Furthermore, preparation of a coherent superposition state is demonstrated using coherent population trapping.

Q 9.4 Mon 17:45 P 3

ODMR on diamond's negatively charged defects based on IV group of elements — •Petr Siyushev, Mathias Metsch, Lachlan Rogers, Aroosa Ijaz, and Fedor Jelezko — Institute for Quantum Optics and IQST, Ulm University, Ulm, Germany

Growing interest to the defects based on elements of IV group of the periodic table such as silicon-vacancy (SiV) or germanium-vacancy (GeV) is stimulated by their good optical properties. Besides high Debye-Waller factor, they exhibit exceptional spectral stability which is rare for solid state systems vulnerable to the surrounding charge fluctuations. This property is dictated by the physical structure of these defects. However, their electronic structure does not allow simple access to electron spin by microwave field which technique is widely used for the well-known NV center. Here, we discuss the way how to overcome this problem and demonstrate optically-detected magnetic resonance on a single GeV defect.

Q 9.5 Mon 18:00 P 3

Robustness of orbital-angular-momentum photons under perturbations. — •Giacomo Sorelli, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs Universität, Freiburg i. Br., Germany

Photons with a helical phase front have a definite orbital angular momentum (OAM) of $l\hbar$, with l an arbitrary integer. Since this spatial degree of freedom spans an infinite-dimensional Hilbert space, it can increase the channel capacity and enhance security of quantum communication. Despite these promising applications, the information encoded in OAM photonic states is fragile with respect to disturbance along the transmission path. In particular, quantum entanglement between photon pairs, which is required for many quantum protocols, rapidly decays when photons propagate through a turbulent atmosphere.

In this talk we compare the robustness of entanglement when encoded in Laguerre Gauss (LG) and Bessel Gauss (BG) modes for two kinds of perturbations. First, we provide an accurate theoretical description of an experiment [1] where entangled biphotons in BG and LG modes were subjected to a circular obstruction. Second, we consider the propagation of such entangled biphotons through a turbulent atmosphere in order to identify which of the two sets of modes is a more resilient one.

[1] M. McLaren et al., Nat. Commun. 5: 3248 (2014)

Q 9.6 Mon 18:15 P 3

Universal entanglement decay of twisted photons in a weakly turbulent atmosphere — •David Bachmann, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität, Freiburg i. Br., Germany

The propagation of entangled twisted photons that carry orbital angular momentum (OAM) through turbulent atmosphere has become a rapidly developing research area. This topic is motivated by the potential uses of the underlying unbounded Hilbert space associated with the OAM for quantum communication. However, atmospheric turbulence introduces random phase shifts to the photons' phase profile, which is used for encoding quantum information, and eventually results in a loss of entanglement. Recently, it has been shown [1] that the entanglement decay of OAM qubit states in a weakly turbulent atmosphere is a universal function of a single parameter – the ratio between the OAM beam's phase correlation length and the turbulence correlation length, but the explicit form of the decay law was not yet obtained.

In this talk, we present analytical expressions for the universal entanglement decay law of a biphoton state in weak atmospheric turbulence. These results are obtained for different models of the turbulence phase structure function, using asymptotic methods. Thereby, we establish the explicit relationship between the turbulence-induced coupling strength between different OAM modes and the specific form of the decay law.

[1] N. D. Leonhard et al., Phys. Rev. A **91**, 012345 (2015).

Q 9.7 Mon 18:30 P 3

Quantum-Limited Measurements of Optical Signals from a Geostationary Satellite — •Kevin Günthner[1,2], Imran Khan[1,2], Dominique Elser[1,2], Birgit Stiller[1,2], Ömer Bayraktar[1,2], Christian R. Müller[1,2], Karen Saucke[3], Daniel Tröndle[3], Frank Heine[3], Stefan Seel[3], Peter Greulich[3], Herwig Zech[3], Björn Gütlich[4], Ines Richter[4], Sabine Philipp-May[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]Tesat-Spacecom GmbH & Co. KG, Backnang, Germany. — [4]German Aerospace Center (DLR), Space Administration, Bonn, Germany.

Quantum key distribution protocols have already been implemented in metropolitan networks all around the world. A promising method to provide the still missing long-haul link between such networks is optical satellite communication. To this end, existing Laser Communication Terminals (LCTs) can be upgraded to be suitable for quantum communication. An important step towards this objective is to precisely characterize the quantum noise behaviour of the system including the channel. We have performed quantum-limited measurements of optical signals from the Alphasat TDP1 LCT in geostationary Earth orbit. We show that quantum coherence is preserved after propagation of the quantum states over 38600 km. An upper bound for the excess noise that the states could have acquired after propagation is estimated [1].

[1] K. Günthner, I. Khan *et al.*, arXiv:1608.03511 (2016).

Q 9.8 Mon 18:45 P 3

Progress on continuous-variable high-speed quantum key distribution compatible with telecom networks — Imran Khan[1,2], Birgit Stiller[1,2,3], Ulrich Vogl[1], •Stefan Richter[1,2], Kevin Jaksch[1,2], Kevin Günthner[1,2], Christian Peuntinger[1,2,4], Dominique Elser[1,2], Christoph Pacher[5], Christoph Marquardt[1,2], and Gerd Leuchs[1,2,6] — [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 — [3]Centre for Ultrahigh Bandwidth Devices for Optical Systems (CUDOS), School of Physics, The University of Sydney, NSW 2006, Australia — [4]Department of Physics, University of Otago, 730 Cumberland Street, Dunedin, New Zealand — [5]AIT Austrian Institute of Technology, Donau-City-Strasse 1, 1220 Vienna, Austria — [6]Department of Physics, University of Ottawa, 25 Templeton, Ottawa, ON, Canada

For efficient and practical quantum key distribution (QKD), high key rates and compatibility with existing communications infrastructure are important aspects. This work shows the recent progress of our group in Erlangen on the implementation of a continuous-variable QKD setup achieving GHz transmission rates in a telecom fiber environment. We discuss the challenges of employing modulation schemes like quadrature phase-shift keying (QPSK) and Gaussian-modulated coherent states (GMCS). We also demonstrate the experimental feasibility of these schemes for our setup using optical heterodyne detection in the GHz regime.

Q 10: Quantum Effects: QED II

Time: Monday 17:00–18:30 Location: P 4

Q 10.1 Mon 17:00 P 4

Ab-Initio Description of Photoinduced Processes Beyond Classical Maxwell Theory — •Norah Hoffmann, Christian Schaefer, Heiko Appel, and Angel Rubio — Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany

In common methods for the ab-initio description of photoinduced processes such as the visual process, photosynthesis or solar cells, typically the classical Maxwell's equations are employed to describe the propagation of light. The applicability of these equations has been demonstrated since decades for a wide range of physical phenomena and parameter regimes. However, considering the ultimate limit of single molecules interacting with a few photons, the classical description of the electromagnetic field does not suffice anymore. In this case the quantum nature of the electromagnetic field has to be taken into account and therefore existing ab-initio approaches have to be extended. In the present work we face the question: Whether and what changes in the analysis and simulation of photoinduced processes by going beyond the classical Maxwell description. Here the idea of exact factorization, introduced for electron-nuclear problems, will be generalized to electron-photon systems, by considering the recently established multi scale implementation of the Maxwell-equations in the octopus code as Ehrenfest limit for quantum electrodynamics. We apply our novel approach to spontaneous and stimulated emission for atoms and molecules in optical cavities and investigate laser pulses with orbital-angular momentum to address recent experiments with chiral light.

Q 10.2 Mon 17:15 P 4

Coulomb interaction in generic environments — •Pablo Barcellona, Robert Bennett, and Stefan Yoshi Buhmann — Institute of Physics, Albert-Ludwigs University of Freiburg

We consider the the Coulomb force between two point charges in general environments, constituted by magnetodielectric bodies. The environment is taken into account via the classical Green tensor. We describe the interaction as arising from the exchange of one photon between the pair of charges, using time-independent perturbation theory. Screening for spatially-dispersive media, polarization effects for non-translationally invariant systems and local-field corrections are included and discussed. In the limit of dilute polarizable media we recover the interaction between a charged particle and a polarizable molecule.

Q 10.3 Mon 17:30 P 4

Van der Waals interaction at finite temperature — •Helge Dobbertin[1], Pablo Barcellona[2], Manuel Donaire[3], Stefan

Yoshi Buhmann[2], and Stefan Scheel[1] — [1]Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany — [3]Laboratoire Kastler Brossel, ENS-CNRS-UPMC et Collège de France, 4 place Jussieu, 75252 Paris, France

Dispersion forces such as van der Waals forces originate from electromagnetic field fluctuations, both quantum and thermal. One would expect a significant influence of the thermal fluctuations, e.g. in thermal vapors of Rydberg atoms, where strong van der Waals interactions have been demonstrated [1]. On the other hand, it is known that Rydberg dispersion interactions can become temperature-independent due to subtle cancellations [2]. Here, we present a general theory for the van der Waals interaction of excited atoms at finite temperature in the presence of macroscopic bodies within the framework of macroscopic quantum electrodynamics. We show limiting cases of high temperature and discuss under which conditions temperature dependence or independence can be expected.

[1] T. Baluktsian et al., Phys. Rev. Lett. **110**, 123001 (2013).
[2] S. Å. Ellingsen et al., Phys. Rev. A **84**, 060501(R) (2011).

Q 10.4 Mon 17:45 P 4

Semiclassical picture for electron-positron photoproduction in strong laser fields — •Sebastian Meuren, Christoph H. Keitel, and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

Inside a strong laser field electrons/positrons emit photons via nonlinear Compton scattering and photons decay into electron-positron pairs via the nonlinear Breit-Wheeler process [1]. Under certain circumstances a cascade of these fundamental processes develops and theoretical calculations become intricate. All known approaches, which are feasible in this regime, are based on the semiclassical approximation, which separates the classical propagation of the particles from the actual quantum transitions. Approximately, the latter happen instantaneously and essentially as if the external field were a constant-crossed field [2]. It was pointed out, e.g., in [3] that the standard approach is not capable of reproducing the details of the spectrum. In [4] we have shown that also the substructure of the spectrum is correctly described if the semiclassical approximation is applied on the amplitude rather than the probability level of a Feynman diagram.

[1] Di Piazza et al., Rev. Mod. Phys. **84**, 1177 (2012)

[2] V. I. Ritus, J. Sov. Laser Res. **6**, 497 (1985)

[3] C. N. Harvey et al., Phys. Rev. A **91**, 013822 (2015)

[4] SM, C. H. Keitel and A. Di Piazza, Phys. Rev. D **93**, 085028 (2016)

Q 10.5 Mon 18:00 P 4

Simulating strong control fields in nuclear quantum optics — Kilian P. Heeg[1], Andreas Kaldun[1], Cornelius Strom[2], Patrick Reiser[1], Johann Haber[2], Hans-Christian Wille[2], Stefan Goerttler[1], Rudolf Rüffer[3], Christoph H. Keitel[1], Ralf Röhlsberger[2], Thomas Pfeifer[1], and •Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [3]ESRF-The European Synchrotron, Grenoble, France

X-ray quantum optics recently gained considerable momentum, both, theoretically and experimentally. However, a severe practical limitation arises from the fact that suitable strong control laser fields are generally not available. Even x-ray free electron lasers are expected to have only a moderate impact on the nuclei, mostly, due to their narrow line width as compared to the x-ray pulse bandwidth. To circumvent this problem, we are developing methods to simulate the effect of strong control fields in certain configurations, without the need to actually apply any electromagnetic field. In this talk, I will review our recent theoretical and experimental progress in this direction.

Q 10.6 Mon 18:15 P 4

Collective magnetic splitting in single-photon superradiance — •Xiangjin Kong and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 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.

Here, we present a quantitative study of systems of atoms or 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 Zeeman or 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-atom magnetic-field-induced splitting [1]. Only one of these regimes has been so far confirmed experimentally in nuclear condensed-matter systems [2]. Finally, we show that all three regimes should be realizable in planar x-ray cavities with an embedded nuclear layer [3] under experimental parameters available today. Our findings give new and unexpected insights on the collective behaviour of optical and x-ray systems in magnetic fields.

[1] X. Kong and A. Pálffy, arXiv:1606.02988 (2016).
[2] R. Röhlsberger *et al.*, Nature 482, 199 (2012).
[3] X. Kong and A. Pálffy, Phys. Rev. Lett. 116, 197402 (2016).

Q 11: Quantum Optics II

Time: Monday 17:00–18:45 Location: P 5

Q 11.1 Mon 17:00 P 5

Electro-optic polarization modulators for on-chip integration in $LiNbO_3$ based advanced quantum circuits — •Sebastian Brauner[1], Polina Sharapova[2], Harald Herrmann[1], Raimund Ricken[1], Torsten Meier[2], and Christine Silberhorn[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]Universität Paderborn, Computational Optoelectronics and Photonics, Warburger Str. 100, D-33098 Paderborn

Polarization modulation is of key importance for various kinds of quantum processing with single photons. Advanced integrated quantum circuits require compact and reliable modulators which can be directly implemented on-chip.

We demonstrate a wavelength selective integrated electro-optically driven polarization modulator in periodically poled z-cut lithium niobate (PPLN). The operation principle relies on an electrical field driven TE-TM conversion in a Ti-indiffused waveguide exploiting the r_{51} coefficient of the electro-optic tensor. Poling periods in the range of 20 μm enable the required phase-matching for wavelengths in the range of 1.5 μm. Complete conversion, i.e. TE to TM or vice versa, is obtained in our 7.5 mm long waveguide with 21.5 V drive voltage in a spectral bandwidth of 3.2 nm.

Besides experimental investigations using classical light for device characterization, we present detailed theoretical and experimental studies in the quantum regime in particular for biphoton wave packets generated e.g. via parametric down-conversion in the same chip.

Q 11.2 Mon 17:15 P 5

Towards optimized single mode Rubidium exchanged waveguides in KTP for quantum optical applications — •Laura Padberg, Christof Eigner, Matteo Santandrea, Raimund Ricken, Helge Rütz, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Single mode and periodically poled potassium titanyl phosphate (KTP) waveguides are very attractive for non-linear processes in integrated quantum optics. They have been used for many different processes such as photon pair generation in telecommunication bands or coupling of photons between atomic quantum memories in the UV range to communication applications in the infrared. Moreover, a PDC source in the visible is attractive for quantum cryptography, as it allows the use of low-cost Si-APDs detectors as well as it could be coupled to ionic traps. However this technological platform is still in an exploratory stage and therefore the production of each device needs to be optimized depending on the required performances.

Rubidium-potassium-ion exchange is a practical approach for waveguide fabrication in KTP. In-house fabrication of single mode waveguides allows us to control the Rb-exchange parameters to achieve the desired results in terms of guided mode profile and waveguide losses. We show our approach in manufacturing single mode, low loss waveguides in Rb:KTP at 800nm and 1550nm. Moreover we present our progress in manufacturing PDC sources for generation of photon pairs at 800nm.

Q 11.3 Mon 17:30 P 5

Highly efficient frequency conversion with bandwidth compression of quantum light — •Markus Allgaier[1], Vahid Ansari[1], Linda Sansoni[1], Christof Eigner[1], Viktor Quiring[1], Raimung Ricken[1], Georg Harder[1], Benjamin Brecht[1,2], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn, Germany — [2]Clarendon Laboratory, Department of Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Hybrid quantum networks rely on efficient interfacing of dissimilar quantum systems such as parametric down-conversion sources, quantum dots or atoms. However, these are are fundamentally different in frequency and bandwidth of their spectra. While optical pulse manipulation has been demonstrated in many different systems, there is none that combines efficient bandwidth compression and substantial frequency translation. Here, we present a device that achieves both goals using an engineered sum-frequency conversion process in Lithium Niobate. We show the conversion of pure photons at telecom wavelengths from a parametric down-conversion source to the visible range while compressing the spectral bandwidth by a factor of 7.47 under preservation of non-classical photon-number statistics. We achieve internal conversion efficiencies of 61.5 %. With external efficiencies of 16.5 % our experiment significantly outperforms spectral filtering; at the achieved bandwidths this represents a gain in efficiency of 26 %.

Q 11.4 Mon 17:45 P 5

Bridging the UV-IR gap: Fabrication and characterization of an integrated frequency converter — •Matteo Santandrea, Helge Rütz, Christof Eigner, Laura Padberg, Raimund Ricken, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

One of the basic building blocks of quantum networks will be interfaces between different physical systems, e.g. between atoms and low loss fibers. The transition wavelengths of atoms and ions often lie in the ultraviolet spectral range; therefore, it is necessary to develop devices able to bridge the gap between these two wavelength ranges. Periodically-poled, rubidium-exchanged potassium titanyl phosphate (PP Rb:KTP) waveguides are ideally suited interfaces, thanks to their high photorefractive damage resistance and the possibility to achieve poling periods in the μm range.

We designed and fabricated a PP Rb:KTP waveguide to perform sum frequency generation (SFG) between 397 nm and 1564 nm in order to interface a $^{40}Ca^{+}$ quantum memory with a standard telecom fiber network in the C-band.

Here, we want to present the measured properties, both linear and nonlinear, of our first working prototype and discuss how to further improve the performance of the device.

Q 11.5 Mon 18:00 P 5

Demonstration of a low-noise quantum memory in Cs vapour — Krzysztof T. Kaczmarek, Patrick M. Ledingham, •Benjamin Brecht, Sarah Thomas, Joseph H. D. Munns, Amir Feizpour, Dylan J. Saunders, Joshua Nunn, and Ian A. Walmsley — Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom

Quantum memories will play a pivotal role in the realization of large-scale quantum networks. In such architectures, they will serve as both active and passive network nodes.

Here, we realise a quantum memory in warm atomic Caesium vapour. Our memory is based on a so-called ladder protocol, which combines low-noise operation with outstanding experimental simplicity. We demonstrate the storage and retrieval of heralded single photons from a parametric down-conversion source. Both the stored and retrieved photons feature a heralded $g^{(2)}(0)$ correlation of less than 0.5, which verifies the successful memory operation.

Q 11.6 Mon 18:15 P 5

Spin-orbit coupling of photons emitted by a single ion — •Gabriel Araneda[1], Daniel Higginbottom[2], Jürgen Volz[3], Arno Rauschenbeutel[3], Yves Colombe[1], and Rainer Blatt[1,4] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck, Austria — [2]Australian National University, Canberra ACT 0200, Australia — [3]Vienna Center for Quantum Science and Technology, TU Wien - Atominstitut, Stadionallee 2, 1020 Vienna, Austria — [4]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, A-6020 Innsbruck, Austria

The photon emission process in an atom conserves the total angular momentum of the atom-photon system. The angular momentum carried by the photon can be present as spin angular momentum, corresponding to the polarization of the light, and orbital angular momentum, which is related to the phase fronts of the radiated field. We present an experiment where the photons detected in a given direction carry solely orbital angular momentum. In this configuration, the apparent position of the emitter is shifted depending on the σ^+ or σ^- polarization of the emitted photons. The expected displacement is λ/π, where λ is the wavelength of the emitted photons. We detect σ^+ and σ^- photons in a direction perpendicular to the quantization axis, and observe a displacement of the apparent location of the ion that is compatible with the expected λ/π value.

Q 11.7 Mon 18:30 P 5

High temperature superconducting surface ion traps. — •Kirill Lakhmanskiy[1], Philip Holz[1], Dominic Schärtl[1], Muir Kumph[2], Yves Colombe[1], and Rainer Blatt[1,3] — [1]Institute for Experimental Physics, University of Innsbruck, Austria — [2]IBM Thomas J. Watson Research Center, USA — [3]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria

Ion traps are used as a tool to perform quantum simulations [1] and quantum computation [2]. One approach to achieve large scale quantum systems is to utilize surface ion traps. However, the closeness of the ions to the trap's surface leads to an increase of the heating rate of the motional state, which degrades the fidelity of quantum operations. The origin of this heating is not well understood [3]. To investigate different sources of motional heating, we operate a surface ion trap made of YBCO, a high-temperature superconducting material. The trap is designed in such a way that Johnson noise should be the dominant source of motional heating above the critical temperature Tc∼85 K, whereas below Tc it should be negligible compared to other noise sources. By measuring the motional heating rate of a trapped ion, we observe large changes in the magnitude of the electric field noise in a small temperature range around Tc, which is consistent with our calculations of the Johnson noise.

[1] R. Blatt and C.F. Roos, Nature Phys. 8, 277 (2012)
[2] R. Blatt and D. Wineland, Nature 453, 1008 (2008)
[3] M. Brownnutt, M. Kumph, P. Rabl, and R. Blatt, Rev. Mod. Phys. 87, 1419 (2015)

Q 12: Nano-Optics I

Time: Monday 17:00–19:00 Location: P 11

Q 12.1 Mon 17:00 P 11

Temperature dependent spectral properties of single point defects in hexagonal boron nitride — •Bernd Sontheimer[1], Merle Braun[1], Nikola Sadzak[1], Igor Aharonovich[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Belrin — [2]University of Technology Sydney

Hexagonal boron nitride (hBN) is an emerging twodimensional wide-bandgap material.[1] Point defects in hBN show extraordinary bright single photon emission at various wavelengths in the visible and near infrared. Here we present our latest research on the temperature dependence of the spectral properties of different individual emitters in mono- and few-layer hBN flakes. Additionally, we show and analyze the apparent spectral diffusion at different time scales as well as optical

coherence properties at cryogenic temperatures.
[1] Tran T., et al., Nat. Nanotechnol. 11, 37-41 (2016)

Q 12.2 Mon 17:15 P 11

Bright multicolor single photon emitter in hexagonal boron nitride at room temperature — •Merle Braun[1], Bernd Sontheimer[1], Igor Aharonovich[2], and Oliver Benson[1] — [1]Nano-Optics, Institute of Physics, Humboldt-Universität zu Berlin — [2]School of Mathematical and Physical Sciences, University of Technology Sydney

Single photon emitters play an important role in a variety of quantum technologies, including quantum communications and computing. The well studied color centers in diamonds present one way to produce single photons. Another promising solid state material are two dimensional hexagonal boron nitride flakes. Due to the wide bandgap, included point defects allow generating single photons at different wavelengths. Here we report our study of the optical properties at room temperature and further our recent successes in preparing samples of hexagonal boron nitride flakes. We detected single photon emitters across the visible and near infrared spectral range (620nm - 750nm) using non-resonant excitation and took spectra, showing the expected intensity distribution: the main emission is within the zero phonon line, indicating a very high Debye-Waller factor. Even at room temperature all these stable emitters showed narrow linewidths below 5 nm as well as very short lifetimes below 5 ns, which lead to a high brightness. This property is an important requirement for many quantum optical experiments.

Q 12.3 Mon 17:30 P 11

Non-linear excitation of single quantum emitters in hexagonal boron nitride — •Andreas w. Schell[1], Hideaki Takashima[1], Toan Trong Tran[2], Igor Aharonovich[2] und Shigeki Takeuchi[1] — [1]Kyoto University, Kyoto, Japan — [2]University of Technology, Sydney, Australia

Recently, two-dimensional materials have gained much interest for various applications in nanophotonics and quantum optics, as they possess a strong luminescence and are able to host single quantum emitters. Excitation of quantum emitters via a two-photon process can be employed for high resolution imaging and has applications in quantum optics. Here, we present one- and two-photon excitation of single defects in hexagonal boron nitride (hBN) and analyse the properties of the emitted light [1]. We find clear antibunching signals that prove the single emitter character in both excitation cases. To gain further knowledge, we also obtain saturation curves. From a comparison of one- and two-photon case insights about the level structure of the defects can be obtained. These results will not only help the fundamental understanding of defects in hBN, but also help to introduce this class of emitters in optical imaging, as the defects in hBN are of small spatial extend, photostable and emit their fluorescence well in the wavelength region of the biological optical window. [1] A. W. Schell et al. APL Photonics 1, 091302 (2016)

Q 12.4 Mon 17:45 P 11

Studies on single perylene bisimide macrocyclesat strong photo-excitation — •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

Quantum emitters like individual organic guest molecules within a matrix can serve as non-classical light sources in quantum communication and metrology applications. In this context, single Perylene Bisimides (PBIs) are interesting candidates for single photon emitters due to their chemically tunability, strong fluorescence and high photostability [1].

Using a confocal-microscopy set-up in combination with fluorescence correlation measurements we characterize the optical properties of PBIs as single quantum emitters at various excitation powers. We will highlight the rich excitation dynamics of para-xylylene bridged PBI-macrocycles and compare them to single chromophores:

At low excitation densities PBI-macrocycles act as bright and stable single photon emitters due to a fast energy transfer between the different chromophores of the macrocycle. Above intensity saturated excitation the co-existence of multi-excitonic states on the macrocycle becomes more likely and the process of exciton-exciton-annihilation controls the emission characteristics. We provide a model to consistently explain our observations and to advance the understanding of excitation and relaxation processes in multi-chromophoric systems.

[1] F. Schlosser et al., *Chem. Sci.* **3**, 2778 (2012)

Q 12.5 Mon 18:00 P 11

Generation of single photons with tailored waveforms using a quantum dot emitting near the Rb D2 line — •Janik Wolters[1], Jan-Philipp Jahn[1], Lucas Beguin[1], Mathieu Munsch[1], Yongheng Huo[2], Fei Ding[3], Rinaldo Trotta[2], Markus Reindl[2], Oliver G. Schmidt[3], Armando Rastelli[2], Philipp Treutlein[1], and Richard J. Warburton[1] — [1]University of Basel — [2]Johannes Kepler University Linz — [3]IFW Dresden

Semiconductor quantum dots are excellent single photon sources, providing triggered single photon emission at a high rate and with high spectral purity. Independently, atomic ensembles have emerged as one of the best quantum memories for single photons, providing high efficiency storage and long memory lifetimes. We have recently demonstrated the emission of high quality photons from a single droplet quantum dot emitting at the Rb D2 transition [1]. However, there is a significant mismatch between the large bandwidth of the quantum dot photons and the relatively small bandwidth of a Rb ensemble. We present here a route to creating photons with a tailored waveform by exploiting a long-lived hole spin in a droplet quantum dot. The quantum dot spin is prepared in one of the spin states and is then driven into the other spin state by a control laser whose waveform determines the waveform of the photon. We demonstrate the creation of $10-100$ ns duration waveforms with single-photon character thereby overcoming the bandwidth mismatch.

[1] J.-P. Jahn *et al.*, Phys. Rev. B **92**, 245439 (2015)

Q 12.6 Mon 18:15 P 11

QD single photons delayed in cesium vapor — •Tim Kroh[1], Janik Wolters[2], Alexander Thoma[3], Stephan Reitzenstein[3], Rinaldo Trotta[4], Eugenio Zallo[5], Armando Rastelli[4], Oliver G. Schmidt[6], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin — [2]Universität Basel — [3]Technische Universität Berlin — [4]Johannes Kepler Universität Linz — [5]Paul-Drude-Institut für Festkörperelektronik, Berlin — [6]IFW Dresden

In forthcoming quantum networks various quantum systems might be involved to accomplish individual tasks, including storage of quantum states, quantum logic operations, error correction, or entanglement distillation. An interface between a single photon emitter and a potential photon storage could provide one fundamental building block of such a hybrid quantum system.

In our experiment this is realized by setting the exciton emission of a strain-tunable InGaAs quantum dot to the cesium D1 line at 894 nm. Under pulsed, non-resonant excitation the QD single photons are delayed in atomic cesium vapor by strong dispersion between two hyperfine-split levels of the D1 transition. This allows for delay times of a few nanoseconds even at low optical densities, resulting in a propagation velocity at the order of 1/20 of the vacuum speed of light. Such a single photon - atom interface might lay the foundations for a low-loss quantum memory in a future hybrid quantum network.

Q 12.7 Mon 18:30 P 11

A deterministic twin-photon source in the solid-state — •Tobias Heindel[1], Alexander Thoma[1], Martin von Helversen[1], Marco Schmidt[1,2], Alexander Schlehahn[1], Manuel Gschrey[1], Peter Schnauber[1], Jan-Hindrik Schulze[1], André Strittmatter[1], Jörn Beyer[2], Sven Rodt[1], Alexander Carmele[3], Andreas Knorr[3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Physikalisch-Technische Bundesanstalt, Abbestraße 1, 10587 Berlin, Germany — [3]Institut für Theoretische Physik, Technische Universität Berlin, 10623 Berlin, Germany

To realize an integrated light source capable of emitting non-classical multi-photon states, is a fascinating, yet equally challenging task at the heart of quantum optics. Here, we propose and experimentally demonstrate the efficient, triggered generation of photon twins using the energy-degenerate biexciton-exciton radiative cascade of a single semiconductor quantum dot [1]. For this purpose, we select a quantum emitter whose exciton's finestructure splitting equals the biexciton binding energy. Deterministically integrated within a microlens, this nanostructure emits photon twins at a rate of up to (234 ± 4) kHz. To directly observe the emitted twin-photon state, we employ a photon-number-resolving detection system based on a transition edge sensor, which enables the reconstruction of the emitted photon number distribution.

[1] A. Thoma, T. Heindel et al., A bright triggered twin-photon source

in the solid state, arXiv:1608.02768 (2016)

Q 12.8 Mon 18:45 P 11

Time reordering of paired photons in a dressed three-level cascade — •Max Strauss, Samir Bounouar, Alexander Carmele, Peter Schnauber, Alexander Thoma, Manuel Gschrey, Jan-Hindrik Schulze, Andre Strittmatter, Sven Rodt, Andreas Knorr, and Stephan Reitzenstein — TU Berlin, Hardenbergstrass e 36, 10623 Berlin

The biexcitonic cascade in semiconductor quantum dots can act as a versatile tool for quantum optical experiments, e.g. as a source of polarisation or time-bin entangled photons. In our experiments, we use continuous-wave two-photon excitation to resonantly excite this three level system and observe the emergence of dressed states under strong excitation. Likewise, we evidence the coherent interaction by the observation of two-photon Rabi oscillations in the time domain. Finally, using photon correlation experiments we demonstrate that the time ordering of the emitted photons in the dressed cascade can be manipulated by increasing the strength of the driving laser field.

Q 13: Precision Measurements and Metrology: Optical Clocks

Time: Monday 17:00–19:00 Location: P 104

Q 13.1 Mon 17:00 P 104

Decay channels of the ^{229}Th nuclear isomeric state involving atomic electrons — •Pavlo Bilous and Adriana Pálffy — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117 Heidelberg, Germany

The thorium isotope ^{229}Th is unique due to its nuclear isomeric (*i.e.* long living) excited state with the energy of $E_{\mathrm{iso}} = 7.8$ eV typical for optical atomic transitions. Being a bridge between atomic and nuclear physics, this nuclear transition has very narrow width and high stability to external perturbations, so it can be a key to metrology applications such as a nuclear frequency standard. The excitation and decay channels of this transition may well involve the electronic shell due to the very low value of E_{iso}.

For the neutral atom ^{229}Th, the isomeric state may decay via internal conversion (IC). For ^{229}Th ions this is not the case as the energy E_{iso} is lower than the corresponding ionization thresholds. However, IC from excited electronic states remains energetically allowed. On the other hand, the energy can be transferred to the electronic shell with excitation of an electron to another bound state accompanied by the absorption or emission of a photon (so called electron bridge). This channel can be strongly enhanced if the electronic and the nuclear transitions are on resonance. Here we consider several channels of decay of the nuclear isomeric state involving the atomic electrons and carry out *ab initio* calculations of corresponding rates using multi-configurational Dirac-Fock wave functions for the bound atomic electrons.

Q 13.2 Mon 17:15 P 104

Entwicklung und Aufbau einer kompakten und hochstabilen optischen Frequenzreferenz für den Einsatz auf einer Höhenforschungsrakete — •Markus Oswald[1], Thilo Schuldt[1,2], Klaus Döringshoff[3], Markus Krutzik[3], Vladimir Schkolnik[3], Franz B. Gutsch[3], Achim Peters[3] und Claus Braxmaier[1,2] — [1]Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation (ZARM), Universität Bremen — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bremen — [3]Humboldt-Universität zu Berlin

Hochstabile optische Frequenzreferenzen spielen bei einer Vielzahl von Weltraumanwendungen eine entscheidende Rolle, wie beispielsweise bei der Detektion von Gravitationswellen, der Navigation oder der Erdbeobachtung. Hierbei stellen Frequenzreferenzen auf Basis von molekularem Jod unter Nutzung der dopplerfreien Sättigungs-Spektroskopie eine vielversprechende Technologie für zukünftige Missionen dar, insbesondere hinsichtlich ihrer Stabilität über lange Zeiträume. Im Rahmen des JoKARUS-Projekts (Jod-Kammresonator unter Schwerelosigkeit) soll erstmals ein Jod-Spektroskopiemodul auf einer Höhenforschungsrakete zum Einsatz kommen und so den Weg bereiten für zukünftige Weltraumeinsätze (z.B. NGGM, eLISA). Ausgehend von vorangegangenen Laboraufbauten wurde ein Instrumentendesign entwickelt und hinsichtlich der Anforderungen der Mission an Kompaktheit, Leistungsfähigkeit und Robustheit optimiert und unter Einbeziehung qualifizierter Klebeverfahren auf einer 246 mm x 145 mm Quarzglasplatte integriert. Finanziert durch das DLR aus Mitteln des BMWi (Förderkennzeichen 50WM1646).

Q 13.3 Mon 17:30 P 104

Relative field sensitivities in ^{171}Yb^{+} transitions — •Richard Lange, Nils Huntemann, Christian Sanner, Christian Tamm, Burghard Lipphardt, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The ^{171}Yb^{+} ion exhibits two transitions that are employed in our setup of a single-ion optical frequency standard, the $^2\mathrm{S}_{1/2} \to {}^2\mathrm{D}_{3/2}$ electric quadrupole (E2) [PRA **89**, 023820] and the $^2\mathrm{S}_{1/2} \to {}^2\mathrm{F}_{7/2}$ electric octupole (E3) [PRL **108**, 090801] transition. In order to provide a frequency standard with highest accuracy, deviations from the unperturbed transition frequencies due to external perturbations have to be taken into account and corrected for. In particular, the effects related to external magnetic and electric fields as well as field gradients need to be investigated. The significantly higher sensitivity of the E2 transition frequency to these perturbations allows for an examination of the E3 transition frequency shifts on a magnified scale.

With precise information about the relative field sensitivities, uncertainties in the E3 transition frequency due to field perturbations can be reduced: Shifts of the E3 transition frequency can be corrected more accurately analyzing changes in the E2 transition frequency than measuring the fields and field gradients directly. In this talk we present improved measurement results of the relative field sensitivities of the E2 and E3 transition frequencies and discuss the effects of these results on the uncertainty budgets of our frequency standards.

Q 13.4 Mon 17:45 P 104

First campaigns with PTB transportable optical lattice clock — •J. Grotti[1], S. Koller[1], S. Vogt[1], A. Al-Masoudi[1], S. Dörscher[1], S. Herbers[1], S. Häfner[1], U. Sterr[1], C. Lisdat[1], H. Denker[2], M. Pizzocaro[3], P. Thoumany[3], B. Rauf[3], C. Clivati[3], M. Zucco[3], F. Levi[3], D. Calonico[3], A. Rolland[4], F. Baynes[4], and H. Margolis[4] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Erdmessung - Leibniz Universität Hannover, Schneiderberg 50, 30167 Hannover, Germany — [3]Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91 , 10135 Torino, Italy — [4]National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

A transportable lattice clock based on ^{87}Sr atoms has been built at PTB and successfully tested in the laboratory. The clock showed a stability of $1.3 \cdot 10^{-15}/\sqrt{\tau}$ and a systematic uncertainty of $7.4 \cdot 10^{-17}$. Furthermore, its frequency is in agreement with the stationary system of PTB. The system has been placed inside a car trailer and used for two measurement campaigns: A proof of principle experiment of relativistic geodesy in the Frejus tunnel, at the Italy-France boarder, and a local measurement of the ^{171}Yb/^{87}Sr clock frequency ratio at Torino. These campaigns were performed in collaboration with INRIM, NPL and the Institut für Erdmessung (IfE), Leibniz University Hannover. Results will be shown in the talk. This work is supported by QUEST, DFG (RTG 1729, CRC 1128), EU-FP7 (FACT) and EMRP (ITOC). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Q 13.5 Mon 18:00 P 104

A Sr lattice clock with $6 \cdot 10^{-17}/\sqrt{\tau/\mathrm{s}}$ frequency instability — •Roman Schwarz[1], Sören Dörscher[1], Ali Al-Masoudi[1], Sofia Herbers[1], Dan-Gheorghita Matei[1], Thomas Legero[1], Sebastian Häfner[1], Christian Grebing[1], Erik Benkler[1], Wei Zhang[2], Lindsay Sonderhouse[2], John M. Robinson[2], Jun Ye[2], Fritz Riehle[1], Uwe Sterr[1], and Christian Lisdat[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig — [2]JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309, USA

Optical clocks represent the forefront of frequency metrology enabling applications in relativistic geodesy, tests of fundamental physics, and the search for dark matter. As their systematic uncertainty reaches the low 10^{-18} regime, reducing their frequency instability becomes even more important in order to exploit their potential. Here, we report on recent improvements of the Sr lattice clocks at PTB by phase-locking the interrogation laser to cryogenic Si resonators at 194 THz. Frequency instabilities of $6 \cdot 10^{-17}(\tau/\mathrm{s})^{-1/2}$ are inferred from clock self-comparisons.

This work is supported by QUEST, the DFG within CRC 1128 (geo-Q), CRC 1227 (DQ-*mat*) and RTG 1729, EMPIR within OC18. The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation program and the EMPIR Participating States.

Q 13.6 Mon 18:15 P 104

Evaluation of a magnesium frequency standard and progress towards a frequency measurement — •Klaus Zipfel, Dominika Fim, Nandan Jha, Steffen Rühmann, Steffen Sauer, Waldemar Friesen, Pia Koopmann, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

State-of-the-art optical atomic lattice clocks with fermionic strontium already reached uncertainties in the low 10^{-18} regime [1,2]. In order to operate on that level, a high Q factor and hence a narrow observable linewidth of the clock transition is key for the evaluation of the systematics.

In this presentation, we report on spectroscopy with an observable linewidth of 100 Hz for the $^1\mathrm{S}_0$ - $^3\mathrm{P}_0$ clock transition in bosonic magnesium, which corresponds to the highest Q factor for an optical transition in that species so far. As a consequence, the resolution for evaluating the uncertainties like 2nd order Zeeman and lattice AC-Stark shift increases. We will show the latest results for our systematics and as well present the progress towards an absolute frequency measurement.

[1] B. J. Bloom et al., Nature **506**, 71 - 75 (2014)
[2] T.L. Nicholson et al., Nature Communications **6**, 6896 (2015)

Q 13.7 Mon 18:30 P 104

Ion dynamics and systematic shifts in a multi-ion atomic clock — •Dimitri Kalincev, Jonas Keller, Tobias Burgermeister, Alexandre Didier, Jan Kiethe, André Kulosa, Tabea Nordmann, Thorben Schmirander, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Single ion optical clocks have an estimated systematic fractional frequency uncertainty at the 10^{-18} level. The main limitation in measuring atomic frequencies is their statistical uncertainty due to the fundamental limit of quantum projection noise. In order to exploit the high accuracy, very long averaging times are required. We show that the statistical uncertainty of single-ion-clocks can be overcome with a multi-ion-approach while keeping excellent control of systematics. For mixed crystals, we analyze effects relevant at the 10^{-19} level and below. We identify crystal configurations that can be cooled efficiently while having low heating rates.

With a new chip-based linear Paul-trap, designed for low axial micromotion, we measure heating rates as a function of the ion secular frequency. We simultaneously measure micromotion across an ion Coulomb crystal. Based on experimental results on trap induced shifts and on our calculations, we present an estimated error budget for a multi-ion-clock.

Q 13.8 Mon 18:45 P 104

High precision and high frequency sensing with a continuous drive utilizing the Nitrogen Vacancy center — •Daniel Louzon[1,2], Alexander Stark[1,3], Thomas Undnen[1], Nati Aharon[2], Alexander Huck[3], Ulrik L. Andersen[3], Alex Retzker[2], and Fedor Jelzko[1] — [1]Ulm University, Ulm, Germany — [2]Hebrew University, Jerusalem — [3]Technical University of Denmark, Kongens Lyngby, Denmark

Single defect centers in diamond and especially the nitrogen-vacancy (NV) show remarkable physical properties such as long spin coherence time and the emission of single photons. These properties make them ideal candidates for qubits and nano-scale magnetic field sensors [1].

High frequency sensing, using a two level system, is considered T_2^* limited, given dynamical decoupling techniques cannot be applied on a time scale shorter than the on-resonance signal being measured.

We present the implementation of a novel technique to measure a weak high frequency signal using a detuned two level system and a series of continuous driving fields prolonging the coherence time of the two level system in principle close to its T_1 time [2].

The technique is demonstrated on a single NV center in diamond as the two level system, measuring a weak high frequency signal, with a coherence time over an order of magnitude longer than its T_2^*.

[1] M. Doherty et al., Physics Reports 528, 1 (2013) [2] N. Aharon et al., arXiv: 1609.07812 (2016).

Q 14: Quantum Gases: Bosons II

Time: Monday 17:00–19:00 Location: P 204

Q 14.1 Mon 17:00 P 204

Bose-Einstein condensates and Conical Refraction: Novel Approach to Toroidal Guiding Potentials for ATOMTRONIC Devices — •Felix Schmaltz, Patrick van Beek, Philip Prediger, Felix Weigand, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

We present a novel type of toroidal guiding potential for BEC-based coherent matter waves applicable for atom interferometry or ATOMTRONIC devices such as atomic SQUIDS.

Exploiting the effect of conical refraction in biaxial crystals, we are able to create various types of light field patterns, which can act as dipole force mediated toroidal matter waveguides. Depending on laser beam and crystal parameters, the topology and dimension of these waveguides can be controlled.

Only by changing the waist of the impinging laser beam, the conical refraction light field, using blue detuned light, can be transformed from a harmonical to a toroidal trapping potential. Using dynamically tunable lenses, we can realize the adiabatic transformation of a BEC from a simply connected to a multiply connected trapping topology.

Such a toroidal matter wave can be used to probe superfluidity and vortex-like behavior of confined BECs in a dynamically adjustable fashion.

Q 14.2 Mon 17:15 P 204

Spatially distributed many-particle entanglement in a spinor Bose-Einstein condensate — •Philipp Kunkel, Maximilian Prüfer, Daniel Linnemann, Anika Frölian, Helmut Strobel, Christian-Marcel Schmied, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg

A key resource for distributed quantum-enhanced protocols are entangled states between spatially separated modes. In spinor Bose-Einstein condensates such nonclassical states are routinely generated by short-ranged contact interactions. Here, we use spin mixing in a tightly confined BEC of ^{87}Rb to generate a two-mode squeezed vacuum. Subsequent expansion in a shallow waveguide potential gives rise to nonclassical correlations between opposite spatial directions. Local and global observables are used to quantify the continuous variable entanglement which violates an inequality based on the Einstein-Podolsky-Rosen argument.

Q 14.3 Mon 17:30 P 204

Non-local correlations in interacting bosonic gases - semiclassical results in non-perturbative regimes — •Benjamin Geiger, Quirin Hummel, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

In order to investigate general properties of interacting bosonic gases we present a formalism to calculate thermodynamic properties and the density of states by means of short-time propagation and compare our analytical predictions against quantum integrable models using Bethe ansatz techniques. As an essential input of our approach, we were able to construct the many-body propagator for a one-dimensional free bosonic gas with delta interactions of variable strength. Using this propagator we can give analytical expressions for the smooth part of the many-body density of states as well as spatial two point correlations for the Lieb-Liniger model. We present explicit analytical results for the high-temperature regime which are non-perturbative in the interaction strength and explain numerical observations by Deuar et. al. [1]. Corrections for lower temperatures can be found systematically. A perturbative approach for arbitrary temperatures using Matsubara theory is presented, which is valid in the weakly interacting regime.

[1] P. Deuar et al., Phys. Rev. A 79, 043619 (2009)

Q 14.4 Mon 17:45 P 204

Many-particle quantum dynamics after an interaction quench for ground state quantum bright solitons — •Christoph Weiss[1] and Lincoln Carr[2] — [1]Joint Quantum Centre (JQC) Durham-Newcastle, Department of Physics, Durham University, United Kingdom — [2]Colorado School of Mines, Golden, USA

We investigate attractively interacting bosons in a (quasi-)one-dimensional waveguide initially prepared in the ground state of an additional harmonic potential, a quantum bright soliton. An interaction quench that increases the interaction by a factor of four combined with switching off the potential leads to a higher-order soliton for which the mean-field description via the Gross-Pitaevskii equation predicts oscillations of the variance of the single particle density. By combining numerical investigations using TEBD with analytical Lieb-Liniger results, we show that the soliton breaks apart. This behaviour is visible when measuring the relative distance between particles.

Q 14.5 Mon 18:00 P 204

Understanding quantum phase transitions in the attractive Lieb-Liniger model by quantizing critical mean-field behaviour — •Quirin Hummel, Benjamin Geiger, Juan-Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

We consider a one-dimensional model of Bosons with attractive interactions which is known to display a quantum phase transition (QPT) at a critical value of the interaction strength α. A semiclassical quantization, where a large number of particles N plays the role of small $\hbar$, allows us to find the parameters of the QPT in terms of quantized orbits passing through a separatrix in classical phase space. Moreover it allows us to analytically quantify effects arising from the discreteness of the quantum mechanical spectrum like the scaling of the ground state gap with N right at the critical α (explaining the numerical findings in [1]), and the high-density spectrum around the excited state QPT for larger couplings. We extract the exact time-scale of the latter - also known as the scrambling time - and rigurously show that it is related to a stability exponent of the underlying classical dynamics. Finally, the universal applicability of our ideas whenever the QPT is related to similar classical behaviour, leads us to expect that this semiclassical picture can be applied to a broad class of QPT with effective one-dimensional descriptions (e.g. Dicke model, Lipkin-Meshkov-Glick model).

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

Q 14.6 Mon 18:15 P 204

Signatures of distinguishability in many-body dynamics — •Gabriel Dufour, Tobias Brünner, Maximilian Dirkmann, Alberto Rodriguez, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

The dynamics of ensembles of quantum particles depends on whether these particles can be distinguished from one another. Indeed, the requirement that many-body states be symmetric under the exchange of identical particles leads to intricate interference effects. These effects have mainly been investigated in the case of non-interacting particles, such as photons in interferometers, but they also play a role in the behaviour of interacting particles, e.g. atoms trapped in optical lattices.

We investigate the ways in which the dynamics of distinguishable and indistinguishable particles differ. To do so, we consider ensembles of bosons condensed into a finite number of modes and which can belong to one of several mutually distinguishable “species”. We study the structure of the corresponding Hilbert space and its consequences for the dynamics. Moreover, we identify a suitable measure of the level of distinguishability in the system. These results are illustrated by a study of the dynamics of a two-component Bose-Einstein condensate in a double-well.

Q 14.7 Mon 18:30 P 204

Properties of quantum filaments in dipolar Bose-Einstein condensates — •Falk Wächtler and Luis Santos — Institut für Theoretische Physik, Leibniz Universität Hannover, Hannover, Germany

Recent experiments with the highly magnetic atoms dysprosium and erbium have revealed the formation of stable quantum droplets in dipolar Bose-Einstein condensates. This surprising result has been explained by the stabilization given by quantum fluctuations. We will discuss properties of a dipolar BEC in the presence of quantum stabilization focusing in particular on the low-lying excitations all the way from the mean-field to the droplet regime. Moreover, we will show the effects of three-body losses for the dynamics of droplet formation as well as the role of quantum fluctuations in the strength of the three-body losses. This shows a large increase of the losses in the droplet regime significantly lowering their lifetime.

Q 14.8 Mon 18:45 P 204

Quantum Domain Walls Induce Incommensurate Supersolid Phase on the Anisotropic Triangular Lattice — Xue-Feng Zhang[1,2,3], Shijie Hu[1], •Axel Pelster[1], and Sebastian Eggert[1] — [1]Physics Department and Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Max-Planck-Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [3]State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China

We investigate the extended hard-core Bose-Hubbard model on the triangular lattice as a function of spatial anisotropy with respect to both hopping and nearest-neighbor interaction strength [1]. At half-filling the system can be tuned from decoupled one-dimensional chains to a two-dimensional solid phase with alternating density order by adjusting the anisotropic coupling. At intermediate anisotropy, however, frustration effects dominate and an incommensurate supersolid phase emerges, which is characterized by incommensurate density order as well as an anisotropic superfluid density. We demonstrate that this intermediate phase results from the proliferation of topological defects in the form of quantum bosonic domain walls. Accordingly, the structure factor has peaks at wave vectors, which are linearly related to the number of domain walls in a finite system in agreement with extensive quantum Monte Carlo simulations. We discuss possible connections with the supersolid behavior in the high-temperature superconducting striped phase.

[1] Phys. Rev. Lett. **117**, 193201 (2016)

Q 15: Ultracold atoms and BEC - II (with A)

Time: Monday 17:00–19:00 Location: N 1

Q 15.1 Mon 17:00 N 1

Multiple BECs in a non-degenerate ring cavity — •Deepak Pandey[1,3], Grigor Kuyumjyan[1], Walid Cherifi[1], Naik Devang[1], Andrea Bertoldi[1], Arnaud Landragin[2], and Philippe Bouyer[1] — [1]LP2N, Université Bordeaux, IOGS, CNRS, Talence, France — [2]LNE-SYRTE, Observatoire de Paris, CNRS, UPMC, F-75014 Paris, France — [3]Presently at Institut für Angewandte Physik, Wegelerstr. 8, D-53115 Bonn, Germany

Quantum degenerate gases of neutral atoms are excellent systems with important applications in the study of many body quantum physics, condensed matter physics, precision measurements, and quantum information processing. We demonstrate the creation of multiple ^{87}Rb Bose-Einstein condensates (BECs) in the higher transverse modes of a bow-tie ring cavity at telecom wavelength 1560 nm. The non-degenerate character of the cavity allows splitting and merging of cold ensembles by deforming the trapping potentials inside the cavity. Another cavity resonance at 780 nm will allow us to realize the cavity aided quantum non-demolition measurements to generate measurement induced spin squeezed states.

Q 15.2 Mon 17:15 N 1

Phase coherence and entanglement in Bose-Einstein condensates — •Tilman Zibold, Matteo Fadel, Roman Schmied, Baptiste Allard, Jean-Daniel Bancal, Nicolas Sangouard, and Philipp Treutlein — Department of Physics, University of Basel, Basel, Switzerland

We perform quantum enhanced metrology on an atom chip using internal states of Bose- Einstein condensed ^{87}Rb atoms. State dependent trapping potentials allow for the generation of entangled states such as squeezed states via interatomic interactions. By accounting for the atom number dependent phase shifts in the system we are able to produce strongly squeezed states. Our recent experiments demonstrate that these many-particle entangled states can exhibit Bell correlations [1]. We will discuss experiments on the limitations of phase coherence of squeezed atomic states and recent advances towards a Bell-test with split Bose-Einstein condensates.

[1] Schmied et al. Science 352, 441 (2016)

Q 15.3 Mon 17:30 N 1

supersolidity in a Bose-Einstein condensate — •Andrea Morales, Julian Leonard, Philip Zupancic, Tilman Esslinger, and Tobias Donner — 1Institute for Quantum Electronics, ETH Zürich, Switzerland

Supersolidity is a paradoxical state of matter featuring both the crystalline order of a solid and the dissipationless flow typical of a superfluid. The realization of this state of matter requires the breaking of two continuous symmetries, the phase invariance of a superfluid and the translational invariance to form the crystal. Proposed for Helium almost 50 years ago, experimental verification of supersolidity remained elusive. Here we report on the realization of such a supersolid state of matter.

This state is realized by coupling a Bose-Einstein condensate (BEC) to the modes of two crossed optical cavity modes. Self-organization to individual cavities only breaks a discrete spatial symmetry and realizes a *lattice supersolid*. By equally coupling the BEC to both modes we enhance the symmetry of the system to a continuous one and observe simultaneous self-organization to the two cavities. We measure the high ground state degeneracy of the new supersolid state by measuring the crystal position over many realizations through the light fields leaking from the cavities. We also monitor real time fluctuations in the crystal position by the relative change in the light levels.

Q 15.4 Mon 17:45 N 1

Realization of balanced gain and loss in a Bose-Hubbard model beyond the mean-field approximation — •Daniel Dizdarevic, Kirill Alpin, Johannes Reiff, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, Germany

In recent years there has been a growing interest in non-hermitian and especially $\mathcal{PT}$ symmetric quantum mechanics, since they allow for an effective description of open quantum systems. A quantum system exhibiting $\mathcal{PT}$ symmetry is given by a BEC in a double well with balanced particle gain and loss, which can be described in the mean-field limit by a Gross-Pitaevskii equation with a complex potential. Although a complex potential renders the Hamiltonian non-hermitian, $\mathcal{PT}$-symmetric stationary states with real eigenvalue spectra exist.

We present a possible experimental realization of such a system by embedding it into a hermitian time-dependent four-mode optical lattice, where additional potential wells act as reservoirs and particle exchange happens via tunneling [1]. Since particle influx and outflux have to be controlled explicitly, a set of conditions on the potential parameters is derived. In contrast to previous work, our focus lies on a full many-particle description beyond the mean-field approximation using a Bose-Hubbard model, where especially the differences arising are of interest. Furthermore, we examine whether $\mathcal{PT}$ symmetric stationary states still appear in the limit of low particle numbers.

[1] Kreibich et al., Phys. Rev. A 87, 051601(R) (2013)

Q 15.5 Mon 18:00 N 1

A Homogeneous 2D Fermi Gas — •Klaus Hueck, Niclas Luick, Lennart Sobirey, Jonas Siegl, Thomas Lompe, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Ultracold 2D Fermi gases in the BEC-BCS crossover provide a model system to investigate e.g. the Kosterlitz-Thouless transition to superfluidity. So far ultracold 2D Fermi gases have been studied in harmonic trapping potentials. This results in an inhomogeneous density distribution, which complicates the theoretical description of the system and only allows for the extraction of trap averaged quantities when utilizing non-local measurement methods such as time of flight imaging.

Here, we present our realization of an ultracold 2D Fermi gas trapped in a homogeneous disk-shaped potential. The radial confinement is realized by a ring-shaped blue-detuned beam with steep walls. Additionally a digital micro mirror device can be used to remove residual inhomogeneities and to imprint arbitrary repulsive potentials onto the system. This enables us to study systems in close analogy to e.g. gated 2D electron gases.

Q 15.6 Mon 18:15 N 1

Non-equilibium BCS state Fermi gas — Alexandra Behrle, Timothy Harrison, •Kuiyi Gao, Martin Link, and Michael Koehl — Physikalisches Institut, University of Bonn, Wegelerstrasse 8, 53115 Bonn, Germany

Ultracold Fermi gases with tunable interactions have been widely used to investigate the BEC-BCS crossover in the last decade and superfluidity of Fermi gases with different interactions have shown a variety of rich physics. So far, the focus of research has mainly been on the equilibrium state of an attractive gas of cooper pairs. Non-equilibrium coherent dynamics of the BCS state was proposed for studying collective modes, pair formation and excitations in superconductivity, however, experimental realization has been hindered by the difficulty of performing fast enough perturbations to the system. In this talk, we will show our efforts in preparing and detecting a non-equilibrium BCS-superfluid of fermionic 6Li atoms. We focus on the coherent dynamics with fast modulation and quenched interactions using fast ramps across the Feshbach resonance.

Q 15.7 Mon 18:30 N 1

Pairing in the normal phase of a 2D Fermi gas — •Puneet Anantha Murthy, Mathias Neidig, Ralf Klemt, Marvin Holten, Luca Bayha, Philipp Preiss, Gerhard Zürn, and Selim Jochim — Physikalisches Institut, Universitaet Heidelberg

Paring of fermions is central to our understanding of superfluidity and superconductivity. In their celebrated work, Bardeen, Cooper and Schrieffer (BCS) describe how a pairing instability at sufficiently low temperatures at the Fermi surface leads to a transition from the normal phase to a superfluid for a weakly attractive Fermi gas. The formation of these Cooper pairs is a true many-body effect as it requires the presence of a Fermi sea and according to the BCS theory the pairing starts at the transition temperature. On this poster, we present evidence for pairing also in the normal phase of a two component 2D Fermi gas. We use spatially resolved radio-frequency (RF) spectroscopy to measure the onset of pairing at different interaction strengths across the 2D BEC-BCS crossover. We show that pairing occurs at temperatures significantly higher than the critical temperature for superfluidity. The spatially resolved RF spectroscopy allows us to separate the low- from the high-density regions of our inhomogeneous trap. As a result, we can identify regions where two-body physics is applicable and regions where many body effects take over. We map out a region in the strongly interacting regime, where paring is significantly influenced by the many-body nature of the system and cannot be explained purely by two-body physics.

Q 15.8 Mon 18:45 N 1

Quantum Simulation of Mesoscopic Fermi Systems — •Philipp Preiss, Andrea Bergschneider, Vincent Klinkhamer, Jan-Hendrik Becher, Gerhard Zürn, and Selim Jochim — Universität Heidelberg, 69120 Heidelberg, Germany

Ultracold quantum gases in optical potentials have achieved spectacular progress in the experimental simulation of complex quantum systems. Complementary to many-body experiments, mesoscopic systems comprised of a small number of atoms offer the possibility to study highly entangled quantum states with an exceptional degree of versatility and control.

We are implementing a highly tunable platform to study such correlated few-fermion systems. As already demonstrated in our group, quantum states of 6Li atoms can be prepared with a deterministic atom number and spin configuration, and interactions are tunable via a magnetic Feshbach resonance. We are extending these techniques to a large range of trap geometries, including trap arrays as well as low-dimensional and toroidal systems. A novel readout scheme with single-particle and spin sensitivity allows us to measure spin- and momentum correlations.

The tunable few-fermion system will enable the realization of many novel mesoscopic systems, for example cylindrical optical lattices with unusual periodic boundary conditions. In two-dimensional traps, we will be able to study the formation of shell structure as well as the emergence of fermion pairing in the presence of interactions. I will discuss the status and prospects of our mesoscopic quantum simulator.

Q 16: Quantum Information: Concepts and Methods III

Time: Tuesday 11:00–12:45 Location: P 2

Q 16.1 Tue 11:00 P 2

Witnessing Quantum Squeezing via Binary Homodyne Detection — Christian R. Müller[1,2], •Kaushik Seshadreesan[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Germany.

Ideal homodyne detection provides an observable with a continuous spectrum. In practical situations, however, the observed quantity is always discretized to some extent. This may be due to the specifics of the protocol, such as the discretization of phase space in CV-QKD, or also due to the limited resolution of the implemented analog-to-digital converter. We consider the extreme case of homodyne detection with a resolution of only 1 bit, i.e., where only the sign of the projected quadrature value is accessible. We illustrate the capacity of such a restricted homodyne detector by demonstrating that even extremely weak squeezing of coherent states can be witnessed. We derive the associated error probabilities in discriminating a coherent state from a weakly squeezed state and experimentally validate our findings. Furthermore, we discuss the possibility of detecting squeezed light transmitted in satellite communication with binary homodyne detectors.

Q 16.2 Tue 11:15 P 2

Quantum Cloning of Binary Coherent States - Optimal Transformations and Practical Limits — •Christian R. Müller[1,2,3], Gerd Leuchs[1,2,4], Christoph Marquardt[1,2], and Ulrik L. Andersen[1,2,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Germany. — [3]Department of Physics, Technical University of Denmark, Lyngby, Denmark — [4]Department of Physics and Max Planck - University of Ottawa Centre for Extreme and Quantum Photonics, University of Ottawa, Canada

The notions of qubits and coherent states correspond to different physical systems and are described by specific formalisms. Qubits are associated with a twodimensional Hilbert space and can be illustrated on the Bloch sphere. In contrast, the underlying Hilbert space of coherent states is infinite-dimensional and the states are typically represented in phase space. For the particular case of binary coherent state alphabets these otherwise distinct formalisms can equally be applied. We capitalize this formal connection to analyse the properties of optimally cloned binary coherent states. Several practical and near-optimal cloning schemes are discussed and the associated fidelities are compared to the performance of the optimal cloner.

[1] C. R. Müller et al., arXiv:1609.02136v1 [quant-ph]

Q 16.3 Tue 11:30 P 2

Approximating local observables on projected entangled pair states — •Martin Schwarz, Oliver Buerschaper, and Jens Eisert — FU Berlin, Berlin

Tensor network states are for good reasons believed to capture ground states of gapped local Hamiltonians arising in the condensed matter context, states which are in turn expected to satisfy an entanglement area law. However, the computational hardness of contracting projected entangled pair states in two and higher dimensional systems is often seen as a significant obstacle when devising higher-dimensional variants of the density-matrix renormalisation group method. In this work, we show that for those projected entangled pair states that are expected to provide good approximations of such ground states of local Hamiltonians, one can compute local expectation values in quasi-polynomial time. We therefore provide a complexity-theoretic justification of why state-of-the-art numerical tools work so well in practice. We comment on how the transfer operators of such projected entangled pair states have a gap and discuss notions of local topological quantum order. We finally turn to the computation of local expectation values on quantum computers, providing a meaningful application for a small-scale quantum computer.

Q 16.4 Tue 11:45 P 2

Implications of (quasi)extremal local information for the many-body wave function — •Carlos L. Benavides-Riveros[1], Christian Schilling[2], and Peter Vrana[3] — [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 — [3]Department of Geometry, Budapest University of Technology and Economics, Egry József u. 1., 1111 Budapest, Hungary

The possible compatibility of given density matrices for single site subsystems of a multipartite quantum system 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 propose natural extensions of the Hartree-Fock and Kohn-Sham ansätze based on the corresponding generalized Pauli constraints. This "Muliticonfigurational Self-Consistent Field"-ansatz is tested for a simple model allowing us to reconstruct about 99.5% of the correlation energy.

Q 16.5 Tue 12:00 P 2

Influence of the Fermionic Exchange Symmetry beyond Pauli's Exclusion Principle — 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

Pauli's exclusion principle has a strong impact on the properties and the behavior of most fermionic quantum systems in both, the micro and macro world. Remarkably, a recent mathematical breakthrough has revealed the existence of further constraints on the one-particle picture emerging from the fermionic exchange symmetry. By exploiting those generalized Pauli constraints we develop a measure which allows one to quantify the influence of the exchange symmetry beyond Pauli's exclusion principle. It is based on a geometric hierarchy of Pauli exclusion principle constraints. We provide a proof of principle by applying our measure to a simple model. The corresponding findings conclusively confirm the physical relevance of the generalized Pauli constraints and show that the fermionic exchange symmetry can have an influence on the one-particle picture beyond Pauli's exclusion principle.

Q 16.6 Tue 12:15 P 2

Physical Relevance of Generalized Pauli constraints — •Felix Tennie[1], Daniel Ebler[2], Vlatko Vedral[1,3], and Christian Schilling[1] — [1]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom — [2]Department of Computer Science, The University of Hong Kong, Pokfulam Road, Hong Kong — [3]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543

The fermionic exchange symmetry does not only imply Pauli's exclusion principle but even further constraints on fermionic occupation numbers. For concrete systems, these generalized Pauli constraints are particularly relevant whenever they are (approximately) saturated. In the form of a comprehensive analysis of an analytically solvable model (Harmonium) we explore the occurrence of such (quasi)pinning. By analyzing the strength of quasipinning as function of the particle number, coupling strength, spatial dimension and degree of spin polarization we reveal the mechanism behind it. It is the conflict of energy minimization and fermionic exchange symmetry. Consequently, our results suggest the existence of a microscopic Pauli pressure which forces the system into an approximate saturation of the generalized Pauli constraints.

[1] C. Schilling, D. Gross, and M. Christandl, PRL 110, 040404

(2013).
[2] F. Tennie, D. Ebler, V. Vedral, and C. Schilling, PRA 93, 042126 (2016).
[3] F. Tennie, V. Vedral, and C. Schilling, PRA 94, 012120 (2016).

Q 16.7 Tue 12:30 P 2

A fermionic de Finetti theorem — •Christian Krumnow, Zoltan Zimboras, and Jens Eisert — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany

Mean field approaches have a long and successful history in capturing essential features of quantum systems. One way of rigorously bounding the error made within a mean field approximation is to apply quantum versions of the de Finetti theorem. Those theorems link the symmetry of a quantum state under the swap of subsystems to vanishing quantum correlations. More concretely, they show in the case of finite dimensional quantum lattice systems that a state which is invariant under the swaps of lattice sites is locally indistinguishable from a convex combination of product states.

We present a fermionic version of the de Finetti theorem. It is shown that a state which is insensitive to swaps of fermionic modes loses most of its antisymmetric character and can locally be captured by a separable state.

Q 17: Quantum Repeater and Quantum Communication

Time: Tuesday 11:00–13:00 Location: P 3

Q 17.1 Tue 11:00 P 3

Device-Independent Secret Key Rates for Quantum Repeater Setups — •Timo Holz, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

The device-independent approach to quantum key distribution (QKD) aims to distribute a secret key between two or more parties with untrusted devices, possibly under full control of a quantum adversary. The performance of a QKD-protocol can be quantified by the secret key rate R, which can be lower-bounded via the violation of an appropriate Bell-inequality. We study secret key rates in the device-independent bipartite case for different quantum repeater setups and compare them to their device-dependent analogon [1]. The quantum repeater setups under consideration are the original protocol by Briegel et al. [2] and the hybrid quantum repeater protocol by van Loock et al. [3]. For a given repeater scheme and a given QKD-protocol, the secret key rate depends on a variety of parameters, such as the gate quality or the fidelity of initially distributed states. We investigate the impact of these parameters and suggest optimized strategies.

[1] S. Abruzzo et al., Phys. Rev. A 87, 052315 (2013)
[2] H. J. Briegel et al., Phys. Rev. Lett. 81, 5932 (1998)
[3] P. van Loock et al., Phys. Rev. Lett. 96, 240501 (2006)

Q 17.2 Tue 11:15 P 3

Cavity-enhanced quantum memory at telecommunication wavelength — •Benjamin Merkel, Natalie Wilson, and Andreas Reiserer — Max Planck Institute of Quantum Optics, Garching, Germany

Quantum networks are based on the distribution of entangled photon pairs between distant nodes. Ideally, the photonic links have to operate at telecommunication wavelengths, where loss in glass fibers is minimal, and one has to implement fault-tolerant quantum repeater protocols. The exceptional coherence properties of rare-earth-ions in crystalline hosts have made them a prime candidate for the implementation of such quantum repeaters. In particular, Erbium has an optical transition at a telecom wavelength, for which ensemble-based quantum memories have already been demonstrated. However, the dipole-dipole interaction between densely-packed Erbium ions poses a limit to the achievable coherence time.

To overcome this challenge, we use crystals with a very low impurity concentration. While this minimizes ion-ion interaction and thus enables long coherence times, it comes at the price of a reduced memory efficiency caused by the lower optical depth. We therefore investigate embedding the crystals into optical resonators to enhance the ion-photon coupling. In the limit of weak doping, high resonator quality factor and small mode volume, this approach might even enable us to resolve and control single Erbium ions in a crystal, making them a unique resource for the implementation of global-scale quantum networks.

Q 17.3 Tue 11:30 P 3

An atomic memory suitable for semiconductor quantum dot single photons — •Janik Wolters, Lucas Beguin, Andrew Horsely, Jan-Philipp Jahn, Richard Warburton, and Philipp Treutlein — Universität Basel

Quantum networks will consist of many quantum memory nodes that are interconnected via photonic links, transporting single photons carrying quantum information. In the future, such quantum networks may enable: high-speed quantum cryptography for unconditionally secure communication; large scale quantum computers; and quantum simulators that will allow for exponential speed-up in solving specific complex problems. A promising route towards functional quantum networks is the heterogeneous approach, where different and separately optimized physical systems are used for single photon generation and storage. For example semiconductor quantum dots may be used as efficient, fast and deterministic single photon sources, while atomic ensembles allow for efficient storage of these photons.

We demonstrate a photonic memory in hot Rb vapor with on-demand storage and retrieval. In principle the memory is suitable for storing single photons emitted by an GaAs droplet quantum dot. Operation of the memory is demonstrated using attenuated laser pulses. For pulses with a bandwidth of $\sim$ 100 MHz $\sim 0.5\mu$eV we achieve $\sim 25\%$ storage and retrieval efficiency, while the storage time approaches 1 μs. The developed quantum memory might become a cornerstone for future hybrid quantum dot-atom based quantum networks.

Q 17.4 Tue 11:45 P 3

Memory for photonic polarization qubits with long coherence time — •Matthias Körber, Olivier Morin, Stefan Langenfeld, Andreas Neuzner, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

The ability to faithfully store quantum information is one of the key requirements for many quantum technologies. Here, we present a quantum memory based on a single ^{87}Rb atom in a high-finesse optical resonator, capable of storing and retrieving single-photon polarizaion qubits with an overall efficiency of 18% when probed with highly attenuated coherent laser pulses containing one photon on average. Based on seminal work, the polarization of the photon is mapped onto the atom via a stimulated Raman adiabatic passage (STIRAP). The two atomic levels used to encode the qubit shift in opposite directions in the presence of a magnetic field due to the Zeeman effect. The memory is therefore susceptible to magnetic field fluctuations limiting the coherence time of the memory to a few hundred microseconds. Using an optical Raman transfer we temporarily map the qubit to a protected subspace, thereby extending the coherence time to tens of milliseconds. The coherence time can be further increased to more than 100 milliseconds by means of a spin-echo technique. Our results are an important milestones towards the implementation of a quantum repeater allowing for long distance quantum communication.

Q 17.5 Tue 12:00 P 3

Two-Color Time Entanglement for Quantum Communication — •Tobias Kohl, Chris Müller, and Oliver Benson — AG Nanooptik, Institut für Physik, Humboldt-Universität zu Berlin

Losses over long distances are a big challenge in creating a global quantum communication network. One possibility to minimize those effects is a quantum repeater which can be realized with entangled photons [1]. At certain nodes of a QR these photons have to be matched to dissimilar quantum systems, e.g. a storage or processing unit.

We produce highly non-degenerate photon pairs with wavelengths at the Cs D1 line (894.3 nm) and the telecom O-band (1313.1 nm) by parametric down conversion in a periodically poled Lithium-Niobat crystal. We already demonstrated polarization entanglement [2] when operating in a folded-sandwich geometry. However, polarization is difficult to maintain over long-distance optical fibers. Therefore, we set up a Franson interferometer [3] to create entanglement in time and position.

The goal is to establish a hybrid quantum interface in which we teleport the electronic state of a quantum dot onto a photon at telecom wavelength for long distance communication.

[1] Bussières F., et al. Nature Photonics 8, 775-778 (2014)
[2] Dietz O., et al. Appl. Phys. B 122, 33 (2016)
[3] Franson J. D. Phys. Rev. Lett. 62, 2205 (1989)

Q 17.6 Tue 12:15 P 3

Conversion of polarization to time-bin entanglement for applications in quantum networks — •Chris Müller, Tim Kroh, Andreas Ahlrichs, and Oliver Benson — AG Nanooptik, Institut für Physik, Humboldt-Universität zu Berlin

A key requirement for the acceptance of quantum communication as new technology is its compatibility with existing classical fiber networks. Such a quantum network should also contain quantum repeaters [1], which can be realized using entangled photon pair sources. However, many of the entangled photon sources rely on polarization entanglement, which is challenging to maintain over long-distance fiber networks.

Entanglement in time and position [2] is a suitable candidate for overcoming the loss of polarization entanglement in fibers. We set up a converter which allows for transfer of entanglement from polarization to time and position. In this presentation we want to demonstrate the preliminary results of such a conversion with the goal of using optical fibers for building a quantum network [3].

[1] Bussières F., et al. Nature Photonics 8, 775-778 (2014)
[2] Franson J. D., Phys. Rev. Lett. 62, 2205 (1989)
[3] Kimble H. J., Nature 453, 1023-1030 (2008)

Q 17.7 Tue 12:30 P 3

Quantum Frequency Down-Conversion of Ca^+–Resonant Polarization–Entangled Photons to the Telecom O-Band — •Matthias Bock, Stephan Kucera, Jan Arenskötter, Benjamin Kambs, Sebastian Rühle, Andreas Lenhard, Jürgen Eschner, and Christoph Becher — Universität des Saarlandes, Fakultät NT, FR Physik, Campus E2.6, 66123 Saarbrücken

A typical quantum repeater scenario comprises stationary atomic quantum memories and photonic fiber links to distribute information between these memories. In order to link the photons to the internal states of the atomic system, it is useful to encode the information in their polarization degree of freedom. A drawback is that the typical transition wavelengths in the red or NIR spectral region suffer high losses in optical fibers. Thus, an interface between these transition wavelengths and the low–loss telecom regime, which moreover preserves the polarization state of the photons, is required.

We present the implementation of a polarization–preserving frequency converter connecting 854 nm, the wavelength of the $4^2P_{3/2} \leftrightarrow 3^2D_{5/2}$ transition of a trapped Ca^+–ion, to the telecom O-band at 1312 nm. It is achieved via difference frequency generation in a nonlinear waveguide, which is arranged in a Sagnac configuration to ensure polarization independence. With high external conversion efficiency of 32.5% and low unconditional noise of 50 cts/s we are able to convert photons from a polarization–entangled pair at 854 nm generated by a cavity–enhanced pair source (linewidth: 10MHz) to the telecom O-band, and we show the preservation of the entanglement with high fidelity.

Q 17.8 Tue 12:45 P 3

Towards two-photon interference with a whispering gallery photon pair source — •Gerhard Schunk[1], Golnoush Shafiee[1], Ulrich Vogl[1], Dmitry Strekalov[1], Alexander Otterpohl[1], Florian Sedlmeir[1], Harald G. L. Schwefel[1,2], Gerd Leuchs[1], and Christoph Marquardt[1] — [1]Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany — [2]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. We use parametric down-conversion (PDC) in a whispering-gallery resonator (WGR) made of lithium niobate to generate photon pairs [1] and squeezed light [2]. Single-mode operation of this source has been shown [4]. We recently demonstrated coupling of heralded single photons with MHz-bandwidth to different atomic transitions in the near-infrared [4,5].

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] M. Förtsch et al., Phys. Rev. A 91, 023812 (2015). [4] G. Schunk et al., Optica 2, 773 (2015). [5] G. Schunk et al., J. Mod. Opt. 63, 2058 (2016)

Q 18: Quantum Effects: Cavity QED I

Time: Tuesday 11:00–12:45 Location: P 4

Q 18.1 Tue 11:00 P 4

Real-time generation of predefined atomic patterns inside a cavity — •Eduardo Urunuela, Wolfgang Alt, Jose Gallego, Michael Kubista, Tobias Macha, Miguel Martinez-Dorantes, Deepak Pandey, Lothar Ratschbacher, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

Cavity QED systems are promising candidates for the implementation of Quantum Information protocols. Some of these systems rely on the coherent coupling of single or multiple atoms with an optical field inside a resonator. It is essential to obtain precise control on the number of atoms and their relative position inside the cavity, for instance for specific entanglement generation protocols [1].

In this work, we present an experimental technique to create predefined patterns of a few atoms inside a fiber Fabry-Perot resonator, in real-time. First, several ^{87}Rb atoms are trapped in a 3D optical lattice inside the fiber cavity. Then, using an EMCCD camera, a fluorescence image of the atoms is acquired in situ, and next the atoms in undesired lattice sites are removed using a focused push-out beam, directed by a 2D acousto-optic deflector.

[1] M. J. Kastoryano et al. PRL. 106, 090502 (2011)

Q 18.2 Tue 11:15 P 4

Signatures of Raman-lasing in a side-pumped Ytterbium atom-cavity system — •Hannes Gothe, Anna Breunig, Martin Steinel, and Jürgen Eschner — Universität des Saarlandes, Saarbrücken

A few million Ytterbium atoms are magneto-optically trapped inside a 5 cm long high-finesse cavity using the dipole-allowed $^1S_0 \leftrightarrow {}^1P_1$ line at 399 nm (29 MHz linewidth). The atoms are side-pumped with 556 nm-light (i.e. laser-excited under 90° to the cavity axis) near the $^1S_0 \leftrightarrow {}^3P_1$ intercombination line (182 kHz linewidth), and the scattering into the cavity modes is observed at the output mirrors. Cavity emission is found above a threshold pump intensity and atom number; moreover, the emitted photons show a flat $g^{(2)}$ correlation function. Both observations indicate a lasing process. The conditions and properties of this emission are studied in detail. We will discuss a four-photon Raman process including pump and trap light as the suspected underlying mechanism.

Q 18.3 Tue 11:30 P 4

Hyperradiance from two atoms coupled to a single-mode cavity — •Marc-Oliver Pleinert[1,2,3], Joachim von Zanthier[1,3], and Girish S. Agarwal[2,4] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078, USA — [3]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [4]Institute for Quantum Science and Engineering and Department of Biological and Agricultural Engineering, Texas A&M University, College Station, Texas 77843, USA

We investigate the radiative characteristics of a system consisting of two coherently driven atoms coupled to a single-mode cavity, an ideal setup to study aspects of collective behavior over a wide range of coupling parameters. We show that this fundamental setup can distinctly exceed the free-space superradiant behavior, what we call hyperradiance. The phenomenon is accompanied by strong quantum fluctuations and thus cannot be described by a (semi-)classical treatment. Surprisingly, hyperradiance arises for atoms radiating out-of-phase, an alleged non-ideal condition, where one expects subradiance. We are able to explain the onset of hyperradiance in a transparent way by a photon cascade taking place among manifolds of Dicke states with different photon numbers under particular out-of-phase coupling conditions.

Q 18.4 Tue 11:45 P 4

Two-Photon Blockade in an Atom-Driven Cavity QED System — •Karl Nicolas Tolazzi, Christoph Hamsen, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

N-photon blockade is a dynamical quantum-nonlinear effect in which the absorption of N photons blocks the absorption of N+1 or more photons. This effect occurs in driven systems with an anharmonic ladder of energy eigenstates, e.g. a single atom strongly coupled to a high finesse optical resonator. While single-photon blockade has been demonstrated in such a system before [1], we here report on the first observation of two-photon blockade [2]. As a signature, we show a three-photon antibunching with simultaneous two-photon bunching observed in the light emitted from the cavity. The effect occurs for atom driving, not cavity driving. This can be understood intuitively: while a two-level atom can only add excitations to the system one-by-one, the cavity is not restricted in excitation number. The latter leads to bosonic enhancement which causes the transition strengths between the dressed states to increase with the number of excitations in the system while they remain constant for atom driving. We consider these results as a significant step towards multi-photon quantum nonlinear optics.

[1] Birnbaum et al., Nature 436,87 (2016)
[2] Hamsen et al., arXiv 1608.01571 (2016)

Q 18.5 Tue 12:00 P 4

Coupling a trapped ion to a fiber cavity — •Florian R. Ong[1], Klemens Schüppert[1], Pierre Jobez[1], Dario A. Fioretto[1], Konstantin Friebe[1], Moonjoo Lee[1], Markus Teller[1], Florian Kranzl[1], Konstantin Ott[2], Sebastian Garcia[2], Jakob Reichel[2], Rainer Blatt[1,3], and Tracy E. Northup[1] — [1]Universität Innsbruck, Institut für Experimentalphysik, Technikerstrasse 25, A-6020 Innsbruck, Austria — [2]Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, F-75005 Paris, France — [3]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, A-6020 Innsbruck, Austria

A single atom coupled to an optical cavity can be used as a coherent quantum interface between stationary and flying qubits in a quantum network. Using fiber-based cavities, we expect to reach the strong coupling regime of cavity QED with a single trapped ion. Operating in this regime would enable protocols for quantum communication over long distances to be carried out with enhanced fidelity and efficiency. We will report on our current efforts to couple a calcium ion stored in a linear Paul trap to a fiber cavity. In our setup the cavity is formed between a photonic crystal fiber and a multimode fiber. Both fibers are mounted on separate nanopositioners, enabling us to tune the cavity length and optimize its alignment in vacuum. By developing procedures to control the charges trapped on the fibers' dielectric surfaces, we were able to couple an ion to cavities with lengths of about 500 μm and with finesses in excess of 30,000.

Q 18.6 Tue 12:15 P 4

Coupling ultracold atoms to a superconducting coplanar waveguide resonator — •Helge Hattermann, Li Yuan Ley, Daniel Bothner, Benedikt Ferdinand, Conny Glaser, Lörinc Sárkány, Reinhold Kleiner, Dieter Koelle, and József Fortágh — CQ Center for Collective Quantum Phenomena and their Applications, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

Hybrid quantum systems of superconductors and ultracold atoms have been proposed as a promising candidate for quantum information processing. In such a hybrid system, information is processed by superconducting circuits and stored in an ensemble of trapped atoms, using a superconducting coplanar waveguide resonator as interface between the different quantum systems. Long coherence times of hyperfine superposition states of trapped atoms have already been demonstrated [1], making atoms attractive as a possible quantum memory.

Here, we report on the measurement of the coupling between magnetically trapped ultracold ^{87}Rb atoms and a driven coplanar waveguide resonator which is near-resonant to the atomic hyperfine transition. The field in the cavity is characterized by measuring the frequency shift of the atomic clock states dressed by the cavity field. The determination of this dressing shift for different driving frequencies reveals the lorentzian lineshape of the cavity, in agreement with transmission measurements. This coupling is the first step towards the implementation of an atomic quantum memory for superconducting circuits.

[1] S. Bernon et al., Nat. Commun. 4, 2380 (2013)

Q 18.7 Tue 12:30 P 4

Quantum optical circulator controlled by a single chirally coupled atom — Michael Scheucher, Adèle Hilico, •Elisa Will, Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Austria

Integrated optical circuits for information processing promise to outperform their electronic counterparts in terms of bandwidth and energy consumption. However, such circuits require components that control the flow of light. Here, a particular important class are nonreciprocal devices. Recently, we realized a quantum optical circulator. For this purpose, we strongly couple a ^{85}Rb atom to a whispering-gallery-mode resonator - a so-called bottle microresonator [1] - in which photons exhibit a chiral nature: their polarization is inherently linked to their propagation direction [2]. Interfaced by two optical nanofibers, the system forms a 4-port device. The fact that the atom exhibits polarization-dependent transition strengths leads to a direction-dependent atom-photon interaction. As a consequence, we observe a nonreciprocal behaviour, where photons are directed from one fiber-port to the next [3]. We show that the internal quantum state of the atom controls the operation direction of the circulator [3]. This working principle is compatible with preparing the circulator in a coherent superposition of its operational states. It thus may become a key element for routing and processing quantum information in scalable integrated optical circuits.

[1] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013)
[2] P. Lodahl et al., arXiv:1608.00446v1
[3] M. Scheucher et al., arXiv:1609.02492v1

Q 19: Quantum Optics III

Time: Tuesday 11:00–12:30 Location: P 5

Q 19.1 Tue 11:00 P 5

Topological invariants in one-dimensional lossy quantum walks — •Manolo Rivera[1], Natalie Thau[1], Carsten Robens[1], Wolfgang Alt[1], Janos Asbóth[2], Dieter Meschede[1], and Andrea Alberti[1] — [1]Institut für Angewandte Physik, Bonn, Germany — [2]Wigner Research Centre for Physics, Budapest, Hungary

Quantum walks describe the motion of a quantum particle in discrete steps in time and space. It has been shown that quantum walks enable topologically protected edge states with two associated topological invariants [1]. Furthermore, the number of topologically protected edge states is equal to the difference of the two topological invariants (bulk-boundary correspondence principle). Recent theoretical work suggests that such topological invariants can be measured with a lossy quantum walk [2]. If we perform the split-step protocol and remove one spin species at each time step, the average position where the atom is removed is an integer equal to the sum of the two topological invariants. We here present the topological properties of the split-step protocol and our proposal to achieve the experimental realization of the lossy quantum walk using optimal coin and transport operations in order to measure the topological invariants associated to the unitary split-step quantum walk.

[1] J. K. Asbóth, H. Obuse, "Bulk-boundary correspondence for chiral symmetric quantum walks", Phys. Rev. B 88, 121406(R) (2013)

[2]J. K. Asbóth, T. Rakovszky, A. Alberti, "Detecting topological invariants via losses in chiral symmetric Floquet insulators", arXiv:1611.09670 [cond-mat.mes-hall] (2016)

Q 19.2 Tue 11:15 P 5

Ion traps as heat pumps — •Dawid Crivelli[1], Samuel Thomas Dawkins[1], Ferdinand Schmidt-Kaler[2], and Kilian Singer[1] — [1]Experimentalphysik I, Universität Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel, Germany — [2]Quantum, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany

Thermodynamic machines can be reduced to the ultimate atomic limit [1], using a single ion as a working agent. The confinement in a linear Paul trap with tapered geometry allows for coupling axial and radial modes of oscillation.

A single ion can be driven against the tapered potential, compressing the radial degrees of freedom, which can be then used as a thermal medium. By performing work on the ion, heat is transported from a cold to a hot end of an engineered bath.

Extending the system to multiple ions, the external work induces a directional transfer of heat through the linear crystal. Ions at one side of the trap thus model a finite bath being cooled below its initial, Doppler limited, temperature.

[1] J. Rossnagel et al., "A single-atom heat engine", Science, Vol. 352, Issue 6283, pp. 325-329

Q 19.3 Tue 11:30 P 5

Experimentelle Demonstration einer Wärmekraftmaschine im quantenmechanischen Regime — •David von Lindenfels, Vidyut Kaushal, Johannes Rossnagel, Jonas Schulz, Ferdinand Schmidt-Kaler und Ulrich G. Poschinger — Johannes-Gutenberg-Universität, Mainz

Wir präsentieren eine Wärmekraftmaschine basierend auf einem $^{40}Ca^{+}$-Ion in einer Radiofrequenzfalle. Das Arbeitsmedium ist der Spin des Valenzelektrons, dessen Temperatur durch optisches Pumpen sowie Depolarisation zyklisch geändert wird. Das Ion befindet sich in einer phasenstabilisierten Stehwelle aus verstimmtem Licht mit entlang der Fallenachse alternierender zirkularer Polarisation [1]. Diese ruft über den ac-Stark Effekt eine spinabhängige optische Dipolkraft hervor und koppelt somit den Spin an den axialen Bewegungsfreiheitsgrad, der als Speicher für die gewonnene Arbeit dient. Wir demonstrieren das Anlaufverhalten der Wärmekraftmaschine im quantenmechanischen Regime der axialen Oszillation.

[1] C.T. Schmiegelow et al. PRL **116**, 033002 (2016), Phase-Stable Free-Space Optical Lattices for Trapped Ions

Q 19.4 Tue 11:45 P 5

Distinguishability and many-particle interference — •Stefanie Barz[1], Adrian Menssen[1], Alex Jones[1,2], Ben Metcalf[1], Malte C. Tichy[3], Steve Kolthammer[1], and Ian A. Walmsley[1] — [1]Clarendon Laboratory, Department of Physics, University of Oxford, OX1 3PU, United Kingdom, — [2]Blackett Laboratory, Imperial College London, SW7 2BW, United Kingdom, — [3]Department of Physics and Astronomy, University of Aarhus, DK-8000 Aarhus C, Denmark,

Quantum interference of two independent particles in pure quantum states is fully described by the particles' distinguishability: the closer the particles are to being identical, the higher the degree of quantum interference. When more than two particles are involved, the situation becomes more complex and interference capability extends beyond pairwise distinguishability, taking on a surprisingly rich character. Here, we study many-particle interference using three photons. We show that the distinguishability between pairs of photons is not sufficient to fully describe the photons' behaviour in a scattering process, but that a collective phase, the triad phase, plays a role. We are able to explore the full parameter space of three-photon interference by generating heralded single photons and interfering them in a fibre tritter. Using multiple degrees of freedom—temporal delays and polarisation—we isolate three-photon interference from two-photon interference. Our experiment disproves the view that pairwise two-photon distinguishability uniquely determines the degree of non-classical many-particle interference.

Q 19.5 Tue 12:00 P 5

Hong-Ou-Mandel interference in an integrated quantum optical waveguide device — •Polina Sharapova, Kai Hong Luo, Harald Herrmann, Matthias Reichelt, Christine Silberhorn, and Torsten Meier — Physics department and Center of Optoelectronics and Photonics Paderborn (CeOPP), University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany;

The Hong-Ou-Mandel (HOM) interference is one of the basic and important tools of modern quantum optics. A bulk HOM interferometer includes several quite large optical elements which makes it difficult to use and combine them in compact quantum computational circuits. Technologies that allow to realise quantum optical functionalities in small integrated systems are much more promising in this respect.

In this work we present a theoretical description of a HOM interferometer that can be realised in an integrated quantum optical chip based on, e.g., $LiNbO_3$ waveguide technology. The entire interferometer including several optical elements and the generation of photon pairs via parametric down conversion can be incorporated on a single chip using available fabrication techniques. Our theoretical approach is based on unitary transformations which describe the action of the optical elements and can easily be generalized to more complicated systems.

Q 19.6 Tue 12:15 P 5

Tailoring spatial light modes for sum-frequency generation in Lithium-Niobate waveguides — •Jano Gil López, Vahid Ansari, Markus Allgaier, Harald Herrmann, Raimund Ricken, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098.

Nonlinear optical processes in integrated quantum circuits has shown promising applications in manipulation of quantum states such as spectral bandwidth compression and changing the colour of single photons for interfacing different optical systems. Since it is impossible to design waveguides with single mode characteristics at different wavelengths, a special care has to be taken to tailor the spatial modes of the optical fields inside the waveguide structures.

Here we investigate the tailoring of spatial modes for sum-frequency generation in Lithium-Niobate waveguides for wavelengths between 500 nm to 1550 nm. We present spatially single-mode integrated waveguide circuits for such an optical nonlinear processes.

Q 20: Nano-Optics II

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

Q 20.1 Tue 11:00 P 11

Color centers in pyramidal single crystal diamond scanning probes — •Richard Nelz[1], Philipp Fuchs[1], Oliver Opaluch[1], Selda Sonusen[1], Natalia Savenko[2], Vitali Podgursky[3], and Elke Neu[1] — [1]Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken — [2]Artech Carbon OÜ, Jõe 5, 10151 Tallinn, Estonia — [3]Tallinn University of Technology, Department of Materials Engineering, Ehitajate tee 5, 19086, Tallinn, Estonia

Nitrogen vacancy (NV) color centers in diamond are highly suitable as nanoscale quantum sensors e.g. for optical near fields and magnetic fields; the latter due to their coherent, optically addressable electronic spin [1]. To harness the NV centers' full potential for nanoscale imaging, scannable nanostructures (scanning probes) are required that simultaneously enable efficient extraction of color center fluorescence. However, fabricating such structures in top-down approaches requires extensive efforts in nanofabrication. In contrast, bottom-up approaches can form nanostructures during diamond growth. We here investigate in-situ created color centers in such commercially available single-crystal pyramidal diamond scanning probes and their usability as magnetic field sensors [2]. We summarize our results on fluorescence spectroscopy, spin characterization and numerical investigation of the photonic properties.

[1] L. Rondin et al., Rep. Prog. Phys. **77** 056503 (2014)
[2] R. Nelz et al., Appl. Phys. Lett. **109** 193105 (2016)

Q 20.2 Tue 11:15 P 11

Widefield Microwave Imaging using NV Centres — •Andrew Horsley[1], Janik Wolters[1], Patrick Appel[1], James Wood[1], Jocelyn Achard[2], Alexandre Tallaire[2], Patrick Maletinsky[1], and Philipp Treutlein[1] — [1]University of Basel, Switzerland — [2]LSPM, Universite Paris 13, France

We present a microscope for widefield electromagnetic field imaging using NV centres in diamond. We expect to realise $> 1\,\mathrm{mm}^2$ field of view and sub-ms temporal resolution, exceeding the state-of-the-art for widefield NV imaging. The microscope provides $5\,\mu$m spatial resolution, given by the thickness of the near-uniaxial NV layer, and our current sensitivity is hundreds of $\mathrm{nT\,Hz}^{-1/2}$, which we expect to improve.

We use the microscope for microwave near-field imaging, which we are pursuing in the context of microwave device characterisation [2-4]. Such devices form the backbone of many scientific and technological applications, from quantum devices (atom chips, ion traps, atomic clocks, qubits...) to telecommunications (wifi, mobile phones...). Our technique promises to transform device development, characterisation, and debugging. Our high-resolution NV microscope may also be of interest for medical microwave sensing and imaging, particularly in skin-cancer screening.

[1] Steinert et al., Rev. Sci. Instr. 81, 043705 (2010)
[2] Horsley and Treutlein, APL 108, 211102 (2016)
[3] Horsley, Du, and Treutlein, NJP (FTC), 17(11), 112002, (2015)
[4] Appel et al., NJP (FTC), 17(11), 112001, (2015)

Q 20.3 Tue 11:30 P 11

Kerker Condition based Antenna for Collimation of Single NV Fluorescence — •Niko Nikolay[1], Stefan Fasold[2], Günter Kewes[1], Isabelle Staude[2], and Oliver Benson[1] — [1]Humboldt Universität zu Berlin, Germany — [2]Friedrich-Schiller-University Jena, Germany

The main advantage of plasmonics compared to dielectric structures is their small size - typically in the subwavelength regime [1]. In combination with the concentration of the electromagnetic field in plasmonic antennae, a significant improvement of nanophotonic devices is expected. When high directivities are desired, these advantages however may vanish: Metallic collimating antennas, such as bull's eye or spiral antennas have sizes that are typically significantly larger than the operating wavelength [2]. With increasing size, also losses will become more prominent. When it comes to dielectric nanostructures the Kerker condition can be employed, as such structures can also support magnetic modes [3].

In this contribution we will introduce a dielectric antenna with a subwavelength size and discuss the coupling to the nitrogen vacancy center in nano diamond. Experimental results will be complemented by full numerical calculations.

[1] Schietinger, S. et al.,Nano letters, 9(4), 1694-1698.
[2] Lezec, H. J. et al., Science 297(5582), 820-822.
[3] Kerker, M. et al., JOSA, 73(6), 765-767.

Q 20.4 Tue 11:45 P 11

Radiative heat transfer between spatial nonlocal dielectric sphere and plate — •Robin Schmidt and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, D-18059 Rostock, Germany

With the advances in modern nanophotonics and nanooptics, ever smaller metallic and dielectric structures become feasible. The strongly confined evanescent fields are associated with enormous field enhancements, thus providing heat transfer rates orders of magnitudes larger than feasible in the conventional far-field limit [1]. At nanoscale separation, the thermal heat transfer rate is predicted to diverge for ever smaller separation distances. To overcome this unphysical behaviour, the spatial nonlocal properties of the media under consideration must be taken into account [2,3]. Here, we compute the energy flux between a spatially nonlocal sphere and a plate separated by a vacuum interface. The thermal sources are correlated according to the fluctuation-dissipation theorem. In this linear response regime, spill-out effects can be neglected. Therefore, we employ the Huygens principle and the extinction theorem together with Maxwell boundary conditions [4].

[1] E. Rousseau, *et al.*, Nat. Phot. **3**, 514 (2009).
[2] A. Kittel, W. Müller-Hirsch, J. Parisi, S.-A. Biehs, D. Reddig, and M. Holthaus, Phys. Rev. Lett. **95**, 224301 (2005).
[3] C. Henkel and K. Joulain, Appl. Phys. B **84**, 61 (2006).
[4] R. Schmidt and S. Scheel, Phys. Rev. A **93**, 033804 (2016).

Q 20.5 Tue 12:00 P 11

Universal systematic polarization-dependent errors at the wavelength-scale for position measurements in super-resolution microscopy — •Stefan Walser, Jürgen Volz, and Arno Rauschenbeutel — Atominstitut TU Wien

Super-resolution microscopy is a fast evolving field that revolutionized traditional optical microscopy. Using different techniques, these approaches enhance the precision of optical microscopy significantly beyond the standard resolution limit of $\frac{\lambda}{NA}$ and routinely reach resolutions of a few nanometers. Here we show experimentally that, depending on the polarization of the light emitted by the observed particle, systematic wavelength-scale errors can occur when determining the particle's position using centroid fitting techniques. Surprisingly the observed shifts are universal, i.e., they are independent of the numerical aperture NA or magnification of the imaging optics. We demonstrate this effect by imaging a single gold nano-particle with an optical microscope. We observe a shift of the particle's apparent position of up to 0.3λ when varying the polarization of the light (wavelength : $\lambda = 685nm$) emitted by the nano-particle.

Q 20.6 Tue 12:15 P 11

Three-dimensional XUV Coherence Tomography with nanometer resolution using a supercontinuum HHG source — •Jan Nathanael[1,2], Silvio Fuchs[1,2], Martin Wünsche[1,2], Johann Jakob Abel[1], Julius Reinhard[1], Stefan Aull[1], Max Möller[1,2], Christian Rödel[1,3], and Gerhard G Paulus[1,2] — [1]IOQ, Friedrich-Schiller-University Jena, Germany — [2]Helmholtz Institute Jena, Germany — [3]SLAC Nat. Accelerator Laboratory, USA

We report on recent achievements in the development of XUV Coherence Tomography (XCT), which is based upon the principle of OCT. XCT is a method to resolve multilayer samples at nanometer resolution in axial direction and was proven at synchrotron radiation sources [1]. A suitable lab-scaled XUV source for XCT is a table-top femtosecond laser in combination with a tunable optical parametric amplifier (OPA) as a driver for high-harmonic generation (HHG) due to its spectral broadness. With slightly varying the fundamental frequencies the resulting harmonic combs are shifted. By averaging over these spectra within a few seconds a continuous XUV spectrum is generated in the range of 30 to 200 eV [2]. With this XUV source that features a photon flux up to 3×10^8 photons per eV's XCT can provide non-destructive volumetric three-dimensional measurements with a resolution of about 30 nm axially and 20 micrometer laterally on a lab-scaled HHG setup. Moreover, layers with thicknesses even lower than the achieved axial resolution of XCT can be revealed qualitatively. [1] S. Fuchs et al., Scientific Reports 6, 20658 (2016) [2] M. Wünsche et al., Optics Express, submitted (2016)

Q 20.7 Tue 12:30 P 11

Measuring the Polarizability of Individual Nanoparticles — •Matthias Mader[1,2], Theodor W. Hänsch[1,2], and David Hunger[1,2,3] — [1]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München — [2]Max-Planck-Insitut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]KIT, Physikalisches Institut, Wolfgang-Gaede-Straße 1, 76131 Karlsruhe

Optical characterisation of individual nanosystems gives deep insight into their chemical and physical structure. Getting spectroscopy signals beyond flourescence on a single particle level is very demanding. Here we present a method to quantitatively retrieve the full polarizability tensor of an individual nanosystem within a single measurement using a Fabry-Perot microcavity. [1].

The cavity is built of a micro-machined and high-reflective coated end facet of a single mode optical fibre and a macroscopic plane mirror. By scanning it with respect to the fibre tip, the cavity mode is used as an ultra-sensitive spatially resolving probe for the optical properties of a sample placed on top of the plane mirror. We measure differential frequency shifts as well as the linewidth of several cavity modes to simultaneously infer the sample extinction and dispersion. Combining extinction and dispersion measurements allow for reconstruction of the polarizability tensor of individual paricles.

[1] D. Hunger, T. Steinmetz, Y. Colombe, C. Deutsch, T. W. Hänsch, J. Reichel, New J. Phys. 12, 065038 (2010)
[2] M. Mader, J. Reichel, T. W. Hänsch, D. Hunger, Nature Commun. 6 7249 (2015)

Q 20.8 Tue 12:45 P 11

Progress on quantum-inspired sensing of optically trapped microparticles — •Stefan Berg-Johansen[1,2], Martin Neugebauer[1,2], Peter Banzer[1,2], Andrea Aiello[1,2], Gerd Leuchs[1,2,3], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudstr. 2, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany — [3]Department of Physics, University of Ottawa, 25 Templeton, Ottawa, Ontario, K1N 6N5 Canada

We experimentally demonstrate optical trapping and simultaneous kinematic tracking in three dimensions of a dielectric microparticle using only a single beam. Our approach is based on the nonseparability of polarization and transverse spatial degrees of freedom in cylindrically polarized modes [1,2].

[1] R. J. C. Spreeuw, Phys. Rev. A **63**, 062302 (2001).
[2] S. Berg-Johansen, F. Töppel *et al.*, Optica **2**(10), 864 (2015).

Q 21: Precision Measurements and Metrology: Interferometry I

Time: Tuesday 11:00–13:00 Location: P 104

Q 21.1 Tue 11:00 P 104

Challenging Einstein with Very Long Baseline Atom Interferometry — •Etienne Wodey, Christian Meiners, Dorothee Tell, Dennis Schlippert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

In the quest for a theory of quantum gravity, most of the theoretical attempts to reconcile two of physics' most successful theories, quantum mechanics (QM) and general relativity (GR), build upon a violation of Einstein's equivalence principle. Considerable experimental effort to detect potential violations of the universality of free fall (UFF) has therefore been delivered, first using classical test masses and more recently with genuine quantum objects.

Very Long Baseline Atom Interferometers (VLBAI) represent a new class of matter-wave sensors that extend the baseline from tens of centimeters to several meters, enabling free fall times on the order of seconds and a corresponding increase in the phase sensitivity which scales with the square of the free fall time. Using ultracold mixtures of rubidium and ytterbium atoms, this should not only enable quantum tests of the UFF challenging the current state of the art with classical test masses but also permit new experiments ranging from gravimetry and gradiometry with unprecedented resolution and stability to new probes of the intimate interplay between GR and QM.

The VLBAI facility is a major research equipment funded by the DFG. We also acknowledge support from the CRCs 1128 "geo-Q" and 1227 "DQ-mat" and the RTG 1729.

Q 21.2 Tue 11:15 P 104

Operating an interferometer in a noisy environment — •Dipankar Nath, Henning Albers, Christian Meiners, Logan L. Richardson, Dennis Schlippert, Christian Schubert, Etienne Wodey, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Inertial sensitive devices such as atom interferometers are prone to seismic noise. Atom interferometers with longer baselines are particularly susceptible to very low frequency noise where vibration isolation platforms are not very efficient. Using a mechanical sensor like a seismometer, one can correct the contribution from residual vibrations [1]. We demonstrate seismic post correction in an atom interferometer with 2T=152 ms by correlating the atom interferferometer (operated using cold ^{87}Rb atoms) with a Guralp CMG-40T seismometer and show a two fold improvement in the short term stability using the post correction scheme. Such a scheme will also be implemented in the Very Long Baseline Atom interferometer (VLBAI) [2]. Seismic post correction will also be used to improve the test of the Universality of Free Fall in a dual species atom interferometer employing ^{87}Rb and ^{39}K as test masses [3,4]. Post correction schemes such as this will also be used in atom interferometry based transportable gravimeters in the future.

[1] L. Le Gouët et al., Appl. Phys. B 92, 133 (2008)
[2] J. Hartwig et al., New J. Phys. 17, 035011 (2015)
[3] D. Schlippert et al., Phys. Rev. Lett. 112, 203002 (2014)
[4] B. Barrett et. al., arXiv 1609.03598v1

Q 21.3 Tue 11:30 P 104

Trade-off of atomic sources for extended-time atom interferometry — •Sina Loriani, Dennis Schlippert, Christian Schubert, Ernst Maria Rasel, and Naceur Gaaloul — Leibniz University of Hanover, Germany

Proposals for atom-interferometry based sensors designed to detect gravitational waves or testing the universality of free fall assume unprecedented sensitivity for long interferometry times [Hogan et al., Phys. Rev. A 94, 033632, (2016)]. These long drift times of several seconds can be achieved by operation in microgravity and by using phase-space-manipulation techniqes like the delta-kick-collimation(DKC), which drastically reduces the expansion rate of atomic samples [Müntinga, et al. Phys. Rev. Lett. **110**, 093602 (2013), T. Kovachy et al., Phys. Rev. Lett. **114**, 143004 (2015)]. We present a set of theoretical models that treat the impact of collisions and mean-field on the performance of the kick and compare the efficiency of the collimation for all possible temperature and density regimes. The theoretical study covers commonly used alkaline and alkaline-earth-like ensembles of atoms (Rb, Sr, Yb, etc.). The figure of merit is the size of the ensemble when being lensed as the atomic lenses are subject to aberrations depending on the spatial extent of the cloud and the potentials being used. The analysis shows a clear advantage when using condensed ensembles.

Q 21.4 Tue 11:45 P 104

Infrasound gravitational wave detection with atoms — •Christian Schubert, Dennis Schlippert, Sven Abend, Naceur Gaaloul, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Atom interferometry offers an interesting perspective for the detection of gravitational waves in a frequency band between eLISA and Advanced LIGO, resulting in an active field of research. Ground based setups with vertical or horizontal baselines were considered, satellite missions investigated, and interferometer topologies developed. We investigate a novel geometry for a ground based device combining several advantages as a horizontal baseline, enabling long baselines, a single axis laser link between the atom interferometers acting as phasemeters, and suppressing errors sources otherwise implying very strict requirements onto the atomic source. It is based on recent developments in symmetric large momentum beam splitters, relaunching techniques for suspending the atoms against gravity, and delta-kick collimation techniques to generate very slowly expanding atomic ensembles. The idea will be presented and the requirements discussed in comparison with previous proposals and the state of the art in atom optics. The work is supported by the CRC 1227 DQ-mat, the CRC 1128 geo-Q, the RTG 1729, the DFG Excellence Cluster QUEST, the QUEST-LFS, 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. 50WM1552-1557.

Q 21.5 Tue 12:00 P 104

First gravity gradient measurements with the gravimetric atom interferometer GAIN — •Bastian Leykauf, Christian Freier, Vladimir Schkolnik, Matthias Hauth, Markus Krutzik, and Achim Peters — Institut für Physik, Humboldt-Universität zu Berlin

The gravimetric atom interferometer GAIN is based on interfering ensembles of laser-cooled ^{87}Rb atoms in a fountain setup, using stimulated Raman transitions. GAIN's rugged design allows for transports to sites of geodetic and geophysical interest while maintaining a high accuracy compatible with the best classical instruments. Its long-term stability of $0.5\,\mathrm{nm/s^2}$ and the effective control over systematic effects, including Raman beam wavefront aberrations, has previously been reported [1,2], demonstrating the unique properties of atomic sensors.

By using the juggling technique, we are able to perform gravity measurements on two atomic clouds simultaneously. Advantages include the suppression of common mode phase noise, enabling differential phase shift extraction without the need for vibration isolation. We will present the results of our first gravity gradient measurements.

[1] Schkolnik et al. *The effect of wavefront aberrations in atom interferometry*, Applied Physics B (2015)
[2] Freier et al. *Mobile quantum gravity sensor with unprecedented stability*, Journal of Physics: Conference Series (2016)

Q 21.6 Tue 12:15 P 104

Transportable Quantum Gravimeter – QG-1 — •Maral Sahelgozin[1], Jonas Matthias[1], Nina Grove[1], Sven Abend[1], Waldemar Herr[1], Jürgen Müller[2], Wolfgang Ertmer[1], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Institut für Erdmessung, Leibniz Universität Hannover, Schneiderberg 50, 30167 Hannover

We present the design of our transportable Quantum Gravimeter – QG-1 and report on the progress of the implementation of an ultracold atomic ensemble loaded on our atom chip constituting the source for matter-wave interferometry. The characterization and optimization of our high flux double MOT system will be presented. In our gravimeter the narrow momentum width of the ensemble in combination with higher order Bragg type beamsplitters will be employed to improve the acceleration sensitivity. More crucially the extremely low momentum distribution of an ultracold atomic ensemble will reduce the systematic errors arising from wavefront inhomogeneities during the interrogation time. This is the major limitation to the accuracy of state-of-the-art atomic gravimeters and will be overcome by our absolute quantum gravimeter. By this our compact atom chip based source, miniaturized electronics and simplified telecom fiber based laser system provide a stable and accurate gravimeter for geodetic field applications.

This work is in the scope of the SFB 1128 geo-Q and supported by the Deutsche Forschungsgemeinschaft (DFG).

Q 21.7 Tue 12:30 P 104

Laser-interferometric dilatometry from 100 K to 325 K — •Ines Hamann[1,2], Ruven Spannagel[1,2], Josep Sanjuan[2], Felipe Guzman[1], and Claus Braxmaier[1,2] — [1]University of Bremen, ZARM Center of Applied Space Technology and Microgravity, 28359 Bremen, Germany — [2]DLR German Aerospace Center, Institute of Space Systems, 28359 Bremen, Germany

To enable high precision optical measurements highly dimensionally stable materials are needed. Dimensional stability is an important material property describing the dependency of geometrical dimensions of an optical setup due to temperature fluctuations. Optical setups are often built with components made of glass-ceramics or composite materials which exhibit low coefficients of thermal expansion (CTE). These materials have to be characterized over the full operating temperature range to accurately predict the response of the optical system and the impact on its measurement performance.

Our laser dilatometer setup is designed to characterize these low expansion materials in a temperature range from 100 K to 325 K, using a heterodyne laser interferometer to measure the dimensional changes of a sample due to well-controlled temperature variations. In this talk, we present the current status of our test facility, and recent improvements to decrease the uncertainty budget to levels of 10 ppb/K over the temperature range from 100 K to 325 K.

Q 21.8 Tue 12:45 P 104

JOKARUS: An iodine frequency reference for space-applications on a sounding rocket — •Vladimir Schkolnik[1,2], Klaus Döringshoff[1], Franz Gutsch[1], Markus Krutzik[1], Achim Peters[1,2], and The JOKARUS Team[1,2,3,4,5,6] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]FBH Berlin — [3]ZARM U Bremen — [4]DLR Bremen — [5]JGU Mainz — [6]Menlo Systems GmbH

Stable optical frequency references are a key component in future missions based on quantum sensors testing Einsteins equivalence principle or long baseline interferometers for gravitational wave detection. In this talk, we present JOKARUS: A simple and compact diode laser based frequency reference, stabilized to an optical transition in iodine at 532 nm. Our frequency reference aims to exceed the performance required for space missions such as LISA and GRACE follow on, and will be operated on a sounding rocket flight in Fall 2017 to demonstrate its technological maturity.

The design of our reference system, including diode laser source, gas cell assembly and electronics is presented in detail. JOKARUS is based on the heritage of three successful sounding rocket missions and is adaptable to various wavelengths to reach narrow optical transitions.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant numbers DLR 50WM 1646

Q 22: Quantum Gases: Bosons III

Time: Tuesday 11:00–13:00 Location: P 204

Q 22.1 Tue 11:00 P 204

Laughlin-like states in bosonic and fermionic synthetic ladders — •Marcello Calvanese Strinati — NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR, I-56126 Pisa, Italy

We present a numerical study of one-dimensional Laughlin-like states in bosonic and fermionic ladders, which can be realized in one-dimensional gases with synthetic dimension. Similar to two-dimensional genuine Laughlin states, our system exhibits counter-propagating fractional modes. Laughlin-like states in our systems are identified by specific signatures in the chiral current and entanglement properties. We corroborate our numerical results with an analytical analysis based on bosonization techniques.

Q 22.2 Tue 11:15 P 204

Symmetry-broken states strongly interacting flux-ladders — •Sebastian Greschner[1], Marie Piraud[2], Fabian Heidrich-Meisner[2], Ian McCulloch[3], Uli Schollwöck[2], and Temo Vekua[4] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Department of Physics and Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München — [3]University of Queensland, Australia — [4]James Franck Institute, The University of Chicago, USA

We study the phase diagram of bosonic and fermionic quantum gases in synthetic dimensional flux-ladders in the limit of strong contact interactions. We characterize the panoply of symmetry broken phases including vortex-lattice and biased ladder phases as well as emerging charge-density wave phases at fractional filling or supersolids.

Q 22.3 Tue 11:30 P 204

Quantum Butterfly Effect for Cold Atoms in Optical Lattices: A Trajectory-Based Derivation in Many-Body Space — •Josef Michl, Juan-Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

Recently, it was suggested that $\langle[\hat{V},\hat{W}(t)]^\dagger[\hat{V},\hat{W}(t)]\rangle$, is a suitable measure for quantum chaos and the so-called quantum butterfly effect[1], in the sense that the different ordering of the arbitrary operators $\hat{V}$ and $\hat{W}$ with respect to the time evolution operators is sensitive to the hyperbolicity of the underlying classical system. Simple arguments involving Poisson brackets indeed indicate this average to have terms of exponential increase with a rate related to the classical Lyapunov exponent. This behaviour is expected to hold up to time scales of the classical-to-quantum-crossover, known as Ehrenfest or scrambling time. While numerical studies support this claim, analytical explanations are rare and concentrate more on the exponential behaviour and not on the relation between its rate and the Lyapunov exponent. In this presentation we want to fill this gap using semiclassical methods based on the Van-Vleck-propagator for Bose-Hubbard systems, as the picture of interfering classical mean-field trajectories is well suited to provide a quantitative picture in interacting systems. We explicitly discuss the emergence of the Lyapunov exponent and the involved timescales for the simplified picture of the average of the commutator $\langle[\hat{V},\hat{W}(t)]\rangle$.

[1] J. Maldacena, S. H. Shenker & D. Stanford, J. High Energ. Phys., 2016:106

Q 22.4 Tue 11:45 P 204

Are strategies in physics discrete? A remote controlled investigation — •Robert Heck[1], J. Zoller[2], J. J. W. H.

Sørensen[1], O. Vuculescu[1], M. G. Andreasen[1], M. G. Bason[3], P. Ejlertsen[1], O. Elíasson[1], J. S. Laustsen[1], L. L. Nielsen[1], R. Müller[1], M. Napolitano[1], A. R. Thorsen[1], C. Bergenholtz[1], J. Arlt[1], T. Calarco[2], S. Montangero[2], and J. F. Sherson[1] — [1]Aarhus University, Denmark — [2]IQST Ulm, Universität Ulm, Germany — [3]School of Physics and Astronomy, University of Nottingham, United Kingdom

There exist multiple distinct strategies for the experimental creation of Bose-Einstein Condensates (BEC) of atoms. Besides in purely magnetic traps, BECs can be created in purely optical dipole traps, or by using a hybrid approach of both. We investigate the complex control landscape that arises when these well-known strategies are combined arbitrarily. This addresses the fundamental question if these strategies are unique or if a continuum of good production strategies exists. We find that although each conventional strategy is locally optimal with respect to changes of individual experimental parameters, bridges between the approaches can be identified by appropriate mixing of variables. In a novel approach, the problem was turned into a computer game and citizen scientists from all over the world could contribute in real-time to the optimization of the experiment. The research findings not only yield optimized experimental sequences, but also give insight into cooperative human solving strategies, which could be adapted in advanced computer-based optimization algorithms in the future.

Q 22.5 Tue 12:00 P 204

Losing coherence by a local disturber: ultra-cold bosons scattering in three dimensions — •Valentin Bolsinger[1,2], Sven Krönke[1,2], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We analyze the dynamics of a few interacting, ultra-cold bosons, initially displaced in the longitudinal direction of an anisotropic harmonic trap, scattering with a local disturber. We are interested in the crossover from three towards one dimension and show how both particle correlations and dimensional coupling modify the coherence of the system as well as alter the decay of the center of mass oscillation. In doing so, the many-particle Schrödinger equation is solved by the recently optimized, ab-initio Multi-Layer Multi-Configurational Time-Dependent Hartee method for Bosons (ML-MCTDHB) for three dimensions.

Q 22.6 Tue 12:15 P 204

Periodic Quantum Rabi Model with Ultracold Rubidium Atoms — •Johannes Koch[1], Till Ockenfels[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, which is inaccessible to experiments using natural light-matter interactions. 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 the atoms being trapped in an optical dipole potential. The present status of the experiment will be presented.

Q 22.7 Tue 12:30 P 204

Measuring finite-range phase coherence in an optical lattice using Talbot interferometry — •Christian Baals[1,2], Bodhaditya Santra[1,4], Ralf Labouvie[1,2], Aranya B. Bhattacherjee[3], Axel Pelster[1], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Staudinger Weg 9, 55128 Mainz, Germany — [3]School of Physical Sciences, Jawaharlal Nehru University, New Delhi-110067, India — [4]Zentrum für optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany

The temporal Talbot effect is exploited in our experiment to measure finite-range first-order correlations of a matter-wave field. The working principle relies on the fast blanking of the lattice potential: Upon switching off, the wave-packets at each lattice site expand and interfere with each other. After a variable time, the lattice potential is switched on again resulting in a projection of the time-evolved wavefunction onto the potential landscape of the lattice. The additional energy brought into the system becomes observable in an increase of temperature or excitation of atoms into higher energy bands. At integer multiples of the Talbot time, the atomic density distribution shows revivals, where the emerging contrast depends on the phase coherence between the interfering wave packets. Thereby, later revivals correspond to the interference of matter waves from more distant lattice sites. We apply this interferometer to study the build-up of phase coherence after a quantum quench [arXiv:1611.08430].

Q 22.8 Tue 12:45 P 204

Probing the molecular product-state distribution after neutral three-body recombination — •Markus Deiss[1], Joschka Wolf[1], Artjom Krükow[1], Amir Mohammadi[1], Amir Mahdian[1], Eberhard Tiemann[2], and Johannes Hecker Denschlag[1] — [1]Institut für Quantenmaterie, Universität Ulm, 89069 Ulm, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

The process of three-body recombination, where two atoms form a molecule and a third atom carries away part of the released binding energy, is still hardly understood. In particular, the population distribution of molecular product states is a subject under discussion for lack of experimental data and since the theoretical description is difficult. Here we present first measurements of the product-state distribution of diatomic molecules after three-body recombination for the regime of lowest binding energies. From our spectra, we extract the dependence of the population distribution on the vibrational and rotational excitation, providing important information to test and develop model calculations.

Q 23: Quantum Information: Concepts and Methods IV

Time: Tuesday 14:30–16:30 Location: P 2

Q 23.1 Tue 14:30 P 2

Entanglement and extreme spin squeezing of unpolarized states — •Giuseppe Vitagliano[1], Iagoba Apellaniz[1], Matthias Kleinmann[1], Bernd Lücke[4], Carsten Klempt[4], and Geza Toth[1,2,3] — [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]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

We present optimal criteria to detect the depth of entanglement in macroscopic ensembles of spin-j particles using the variance and second moments of the collective spin components. The class of states detected goes beyond traditional spin-squeezed states by including Dicke states and other unpolarized states. The criteria derived are easy to evaluate numerically even for systems of very many particles and outperform past approaches, especially in practical situations where noise is present. We also derive analytic lower bounds based on the linearization of our criteria, which make it possible to define spin-squeezing parameters for Dicke states. In addition, we obtain also an analytic lower bound to the condition derived in [A.S. Sorensen and K. Molmer, Phys. Rev. Lett. 86, 4431 (2001)]. We also extend our results to systems with fluctuating number of particles.

Q 23.2 Tue 14:45 P 2

Witnessing the metrological efficiency with few expectation values — •Iagoba Apellaniz[1], Matthias Keinmann[1], Otfried Gühne[2], and Géza Tóth[1,3,4] — [1]Department of Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany — [3]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain — [4]Wigner Research Centre for Physics, Hungarian Academy of Sciences, H-1525 Budapest, Hungary

In quantum metrology, the precision of parameter estimation plays a central role. For a given quantum state, the quantum Fisher information characterizes the best achievable precision, hence it is very important to obtain it in an experiment. We show how to estimate the quantum Fisher information as a figure of merit of metrological usefulness based on a few expectation values. Our approach is optimal since it gives a tight lower bound on the quantum Fisher information for the given incomplete information. We apply our method to the results of various multi-particle quantum states prepared in experiments with photons, trapped-ions and cold atomic ensembles, such as spin-squeezed states and Dicke states. Based on a few operator expectation values, our approach can also be used for detecting and quantifying entanglement in very large systems.

Q 23.3 Tue 15:00 P 2

Superfast maximum likelihood reconstruction for quantum tomography — •Jiangwei Shang[1,2], Zhengyun Zhang[3], and Hui Khoon Ng[1,4,5] — [1]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore — [2]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [3]BioSyM IRG, Singapore-MIT Alliance for Research and Technology (SMART) Centre, Singapore 138602, Singapore — [4]Yale-NUS College, Singapore 138527, Singapore — [5]MajuLab, CNRS-UNS-NUS-NTU International Joint Research Unit, UMI 3654, Singapore

Conventional methods for computing maximum-likelihood estimators (MLE) often converge slowly in practical situations, leading to a search for simplifying methods that rely on additional assumptions for their validity. In this work, we provide a fast and reliable algorithm for MLE reconstruction that avoids this slow convergence. Our method utilizes an accelerated projected-gradient scheme that allows one to accommodate the quantum nature of the problem in a different way. We demonstrate the power of our approach by comparing its performance with other algorithms for n-qubit state tomography. In particular, an 8-qubit situation that purportedly took weeks of computation time in 2005 can now be completed in under a minute for a single set of data, with far higher accuracy than previously possible. The same algorithm can be applied to general optimization problems over the quantum state space; the philosophy of projected gradients can further be utilized for optimization contexts with general constraints.

Q 23.4 Tue 15:15 P 2

Time evolution of spin systems in a generalized Wigner representation — •Balint Koczor, Robert Zeier, and Steffen J. Glaser — Department Chemie, Technische Universität München, Lichtenbergstrasse 4, 85747 Garching, Germany

Phase-space representations as Wigner functions are a powerful tool for describing the time evolution of infinite-dimensional quantum systems and have been widely used in quantum optics and beyond. We present a phase-space representation for finite-dimensional quantum systems as coupled spin systems, for which much less is known. This representation is convenient for visualizing arbitrary operators and provides a novel approach for describing and predicting the time evolution without using matrices. Our approach relies on linear combinations of spherical harmonics transforming naturally under local rotations as well as decompositions of operators into sums of tensor products. We illustrate our appraoch with multiple examples for coupled spins systems consisting of up to three spins 1/2.

Q 23.5 Tue 15:30 P 2

Wigner tomography of operators in multi-qubit systems — •David Leiner, Robert Zeier, and Steffen J. Glaser — Department Chemie, Technische Universität München, Lichtenbergstrasse 4, 85747 Garching, Germany

Arbitrary quantum-mechanical operators of a coupled multi-qubit system can be visualized using a Wigner-type representation composed of multiple spherical functions [1]. Building on this approach, we develop a general methodology to experimentally measure these spherical functions. The spherical functions are recovered by computing expectation values of axial spherical tensor operators rotated for a discrete set of angles. Experimental results using nuclear magnetic resonance spectroscopy are presented and visualized for up to three qubits.

[1] A. Garon, R. Zeier, and S. J. Glaser, Physical Review A, 91(4):042122, 2015

Q 23.6 Tue 15:45 P 2

Multiqubit State Tomography from a Physical Perspective — •Lukas Knips[1,2], Christian Schwemmer[1,2], Nico Klein[1,2], Jonas Reuter[3], Géza Tóth[4,5,6], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, D-85748 Garching — [2]Department für Physik, Ludwig-Maximilians-Universität, D-80797 München — [3]Bethe Center for Theoretical Physics, Universität Bonn, D-53115 Bonn — [4]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spanien — [5]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spanien — [6]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Ungarn

We show how the statistical nature of measurements alone easily causes unphysical estimates in quantum state tomography. Multinomial or Poissonian noise results in eigenvalue distributions converging to the Wigner semicircle distribution for already a modest number of qubits. This fact enables to estimate the influence of finite statistics to state tomography as well as the number of measurements necessary to avoid unphysical solutions. More importantly knowing the impact of statistical noise on the eigenvalue distribution directly leads to a physical state estimate with minimal numerical effort. Combining ideas from random matrix theory with pertubation theory, one can immediately obtain a physically motivated estimate together with confidence regions for the state estimate as well as for interesting figures of merit like the fidelity.

Q 23.7 Tue 16:00 P 2

Compressed sensing in quantum state tomography — •Carlos Riofrio and Jens Eisert — Dahlem center for complex quantum systems, Freie Universität Berlin, 14195 Berlin, Germany

As quantum systems get closer to technological applications, the problem of identifying, certifying, and characterizing them becomes more difficult. In fact, a complete characterization of a quantum system requires a computational effort that grows exponentially with the system size. New paradigms that allow for efficient signal processing must be developed and tested in order to overcome this problem. In this talk, we argue that the compressed sensing methodology addresses this issue and present an overview of the most recent developments in quantum state tomography. We show a complete analysis based on experimental data for a 7-qubit system of trapped ions that encodes a single logical qubit in a color code, in which highly incomplete data is observed. In addition, we study the problem of model selection in quantum tomography and observe that for an appropriately chosen regime, compressed sensing is compatible with our heuristic model selection protocol.

Q 23.8 Tue 16:15 P 2

Guaranteed recovery of quantum processes from few measurements — •Martin Kliesch[1,2], Richard Kueng[2], Jens Eisert[3], and David Gross[2] — [1]University of Gdansk, Poland — [2]University of Cologne, Germany — [3]Freie Universität Berlin, Germany

Quantum process tomography is the task of reconstructing unknown quantum channels from measured data. In this work, we introduce compressed sensing-based methods that facilitate the reconstruction of quantum channels of low Kraus rank. The measurements are obtained from sending pure states into the channel and measuring expectation values of observables without the use of ancilla systems. We prove recovery guarantees for three different reconstruction algorithms that using an essentially optimal number of measurements. The reconstructions are based on a trace, diamond, and ℓ_2-norm minimization, respectively. Our recovery guarantees are uniform in the sense that with one random choice of measurement settings all quantum channels can be recovered equally well. Moreover, stability against arbitrary measurement noise and robustness against violations of the low-rank assumption is guaranteed. Numerical studies demonstrate the feasibility of the approach.

Q 24: Quantum Information: Solid State Systems I

Time: Tuesday 14:30–16:15 Location: P 3

Group Report Q 24.1 Tue 14:30 P 3

Entanglement purification in an elementary quantum network — •Andreas Reiserer[1], Norbert Kalb[2], Peter C. Humphreys[2], Jacob J. W. Bakermans[2], Sten J. Kamerling[2], and Ronald Hanson[2] — [1]Quantum Networks Group, MPI für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]QuTech and Kavli Institute of Nanoscience Delft, Delft University of Technology, PO Box 5046, 2600 GA Delft, The Netherlands

Entanglement purification facilitates the generation of high-fidelity entangled states from an ensemble of resource states by eradicating a common statistical contamination. This will be essential for the realization of large quantum networks, in which stationary quantum nodes are connected via noisy photonic channels. Here, we show one round of entanglement purification in an elementary quantum network, consisting of two nodes that each contain two qubits. Using two-photon interference, we first generate entanglement between two of the qubits that are formed by the electronic spins of two nitrogen-vacancy centers in diamond at a separation of 2m. The electronic spin state is then transferred to two nuclear spins in close proximity to the NV centers. The resulting entangled nuclear spin state is kept while the electronic spins are entangled again. Then, the purification protocol is completed via local deterministic two-qubit quantum gates, followed by a fluorescence measurement of the electronic spins. Depending on the measurement result, the nuclear spins are projected to an entangled state of higher fidelity than the two raw states. Our results open the door towards the realization of larger quantum networks.

Q 24.2 Tue 15:00 P 3

Phase-controlled entanglement state generation between distant electron spins — •Lukas Huthmacher, Robert Stockill, Megan J. Stanley, Claire Le Gall, Clemens Matthiesen, and Mete Atatüre — Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge UK

Entanglement is one of the fundamental ingredients for the successful realisation of quantum networks and secure communication schemes. Here, we present the first experimental realisation of distant electron spin entanglement in semiconductor quantum dots. In our experiment, the two InGaAs quantum dots are incorporated in a Mach-Zehnder interferometer, allowing for phase-stable excitation and erasure of which path information. Upon detection of a single photon after the second beam-splitter the electron spins are projected into an entangled state [1]. We confirm the creation of entangled states with an average fidelity of 61.6 ± 2.3%, a violation of the classical limit by 5 standard deviations of the mean. We demonstrate active control over the phase of the entangled state through our choice of the interferometer phase. Combining the outstanding photonic properties of self-assembled quantum dots and the minimal heralding scheme we achieve an entanglement generation rate of 7.25 kHz, the highest reported to date.

[1] Cabrillo, C. et *al.*, PRA **59**, 1025-1033 (1999)

Q 24.3 Tue 15:15 P 3

Heralded control of quantum systems using single spins in diamond — •Durga Bhaktavatsala Rao Dasari, Johannes Greiner, S. Ali Momenzadeh, and Jörg Wrachtrup — 3. Physikalisches Institut, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany.

Steering the evolution of a complex many body system by a well controllable quantum system has applications in various quantum information protocols. Over the past decade a high degree control on the manipulation and measurement of electronic spins attached to single defect centers in diamond has been achieved. Additionally, a well-resolved optical spectrum at low temperatures allows these defect centers to act as good quantum optical systems. We show here how spin-selective optical excitation and readout of electron spins attached to the Nitrogen Vacancy center in diamond can be used to generate quantum correlations in an ensemble of spins, photons and also lead to near ground state cooling of a microcantilever.

Q 24.4 Tue 15:30 P 3

Sensing Weak Microwave Signals by Quantum Control — Timo Joas, •Andreas Waeber, Georg Braunbeck, and Friedemann Reinhard — Walter Schottky Institut and Physik-Department, Technische Universität München, Am Coulombwall 4, 85748 Garching

Solid state qubits, such as the nitrogen vacancy (NV) center in diamond, are attractive sensors for nanoscale magnetic and electric fields, owing to their atomically small size [1]. A major key to their success have been dynamical decoupling protocols (DD), which enhance sensitivity to weak AC signals such as the field of nuclear spins from a single protein [2]. However, those methods are currently limited to signal frequencies up to several MHz.

Here, we present a novel DD protocol specifically designed to detect weak fields close to the NV's transition frequency (≈ 2 GHz). Our scheme is a pulsed version of Autler-Townes spectroscopy [3] with improved spectral resolution. As a result, we demonstrate slow Rabi oscillations with a period up to $\Omega_{Rabi}^{-1} \sim T_2$ driven by a weak signal field. The corresponding sensitivity could enable various applications. Specifically, we consider detectors for radio-astronomy and ultrasound, as well as fundamental research on spin-phonon coupling.

[1] Taylor et al., Nature Physics 4 (2008) [2] Lovchinsky et al., Science 351 (2016) [3] Gordon et al., Appl. Phys. Lett. 105 (2015)

Q 24.5 Tue 15:45 P 3

Multi-qubit quantum memories for improved quantum sensing — •Nikolas Abt[1], Sebastian Zaiser[1], Philipp Neumann[1], Ville Bergholm[2], Thomas Schulte-Herbrüggen[2], and Jörg Wrachrup[1] — [1]3rd Institute of Physics, University of Stuttgart, Germany — [2]Department of Chemistry, Technical University Munich, Germany

Single nitrogen-vacancy (NV) centers in diamond are nanoscale quantum sensors for magnetic and electric fields and temperature, operating even under ambient conditions. Potential applications of such sensors are for example nuclear magnetic resonance (NMR) spectroscopy of nanoscopic samples [1] or steering and characterizing nuclear spin-based quantum simulators [2]. In a sense, NV centers are remote sensors, where the fluorescence response is the only channel to convey measurement results, which is classical information. Proximal ^{13}C nuclear spins couple strongly to the NV center's electron spin and constitute a quantum memory. Recently we have demonstrated the benefit of a single memory qubit for improving sensitivity of an NV center [3]. Here, we scale up the memory register and demonstrate the advantages of metrology information storage and processing for improved quantum sensing. For example, we apply the quantum Fourier transformation for high resolution NMR spectroscopy and obtain multi-bit measurement results.

[1] T. Staudacher, et al. Science 339, 561 (2013).
[2] J. Cai, et al. Nature Physics 9, 1683 (2013).
[3] S. Zaiser, et al. Nature Communications 7, 12279 (2016).

Q 24.6 Tue 16:00 P 3

Towards cavity-enhanced single rare earth ion detection — •B. Casabone[1,2], J. Benedikter[1], T. Hümmer[4], A. Ferrier[3], P. Goldner[3], T. Hänsch[1,4], H. de Riedmatten[2], and D. Hunger[5] — [1]Max Planck Institute of Quantum Optics, Garching — [2]ICFO, The Institute of Photonic Sciences, Castelldefels — [3]Chimie ParisTech, Paris — [4]Ludwig-Maximilians-Universität, München — [5]Karlsruhe Institute of Technology, Karlsruhe

Rare earth ions doped into solids provide outstanding optical and spin coherence properties, which renders them as promising candidates for quantum optical applications ranging from quantum memories to quantum-nonlinear optics. 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[1] 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 10^4), thereby making the weak transitions bright.

We report on the current status of our experiment, where we investigate $Eu3^+$:Y_2O_3 nanocrystals[2] coupled to a cavity in a cryogenic environment.

[1] Hunger, NJP 12, 065038 (2010) [2] Perrot, PRL 111, 203601 (2013)

Q 25: Quantum Effects: Cavity QED II

Time: Tuesday 14:30–16:15 Location: P 4

Q 25.1 Tue 14:30 P 4

Distinguishing models of surface response through the self-energy of an electron — •Robert Bennett[1], Stefan Yoshi Buhmann[1], and Claudia Eberlein[2] — [1]Albert-Ludwigs-Universität Freiburg, D-79104 Freiburg i. Br., Germany — [2]University of Sussex, Falmer, Brighton BN1 9QH, UK

We consider the self-energy of an electron confined between parallel plates, representing a simple model of a cavity. The formalism of macroscopic quantum electrodynamics is used to describe the boundary-dependent fluctuating quantised vacuum field to which the electron is coupled, thereby endowing it with a surface-dependent self-energy [1,2]. After introducing the formalism we will outline the derivation of a general formula for this energy shift and demonstrate that its sign is different for two commonly-used models of surface response, namely the plasma model and the Drude model. Following this we propose a cyclotron-based experiment which could in principle detect this difference in sign, shedding light on continuing disagreements about the correct prescription for the interaction of low-frequency vacuum photons with media.

[1] R. Bennett, S.Y. Buhmann and C. Eberlein: arXiv:1610.01416 [quant-ph]

[2] R. Bennett, C. Eberlein - Physical Review A 86 (6) 062505, 2012

Q 25.2 Tue 14:45 P 4

Propagation of field-matter excitations in a microcavity: an application to photon Bose-Einstein condensation — •Yaroslav Gorbachev, Robert Bennett, and Stefan Yoshi Buhmann — Institute of Physics Albert-Ludwigs University of Freiburg Hermann-Herder-Str. 3 D-79104 Freiburg Germany

The progress of the last few years in photonics has led to new challenges in quantum optics. Especially interesting is a new class of systems which are called quantum fluids of light [1]. In these systems light and matter can be combined to create new types of quasiparticles. These particles differ from vacuum photons and are characterized by effective masses and mutual interactions. We are interested in developing a description of the underlying phenomena in a photon BEC. There, photons thermalize through emission and absorption in a dye medium inside a cavity. We use the language of quantum electrodynamics to describe the propagation of composite field-matter excitations in a dye filled optical microcavity. We will present some preliminary results which are related to this problem.

1: J.Klaers, J.Schmidt, F.Vewinger and M.Weitz. Bose-Einstein condensation of photons in an optical microcavity. Nature, 468(7323): 545-548, 2010

Q 25.3 Tue 15:00 P 4

Cavity-QED beyond model systems — •Christian Schaefer[1], Johannes Flick[1], Heiko Appel[1], Camilla Pellegrini[2], and Angel Rubio[1,2] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Nano-bio Spectroscopy Group and ETSF, Departamento de Fisica de Materiales, Universidad del Pais Vasco UPV/EHU, San Sebastian, Spain

The optimized effective potential (OEP) is a natural connection between local density-functional theory and Many-body perturbation theory. In principle, this variationally best local potential reduces the problem to solving a system of one-particle Kohn-Sham equations combined with the solution of the OEP integral equation. The Krieger-Li-Iafrate (KLI) approximation reduces the integral equation to an analytically solvable one via a dominant orbital approximation.

In the present work, we extend the OEP [1] and KLI approaches to the case of electron-photon interactions in cavity quantum electrodynamics. Here an effective electronic interaction is transmitted via transversal photons. We present first results for KLI and OEP derived from an effectively reformulated Sternheimer response equation [2].

With these approaches, we are able to determine the influence of the quantized electromagnetic field on the electronic configuration of realistic molecules described fully real-space resolved [2,3].

[1] C. Pellegrini et al., Phys. Rev. Lett. **115**, 093001 (2015).

[2] J. Flick, C. Schaefer, H. Appel, C. Pellegrini, and A. Rubio, in preparation

[3] C. Schaefer, J. Flick, H. Appel, and A. Rubio, in preparation

Q 25.4 Tue 15:15 P 4

Microcanonical description of an extended Dicke model — •Miguel A. Bastarrachea-Magnani[1], Sergio Lerma-Hernández[2], and Jorge G. Hirsch[3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany. — [2]Facultad de Física, Universidad Veracruzana, México. — [3]Instituto de Ciencias Nucleares, México.

A paradigmatic model in quantum optics, the Dicke Hamiltonian, describes a system of N two-level atoms interacting with a single monochromatic electromagnetic radiation mode within a cavity. Its algebraic simplicity makes it suitable to describe qubit systems interacting with a bosonic field within the quantum information framework. The model is known because it exhibits a quantum phase transition, both in the ground state and in the excitation spectrum, which can be related to the underlying, classically chaotic spin dynamics, and implies certain entanglement properties. A general question is how the spectral properties of a quantum system are reflected in its thermodynamical phase diagram. In this work it is employed a semi-classical approximation to calculate the thermodynamics of an extended Dicke model in the microcanonical ensemble. The results are compared to calculations for the canonical ensemble. A straightforward thermodynamical manifestation of the critical phenomena on the spectral level is derived.

Q 25.5 Tue 15:30 P 4

Dissipation-Assisted Prethermalization in Long-Range Interacting Atomic Ensembles — Stefan Schütz[1,2], •Simon B. Jäger[1], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]icFRC, IPCMS (UMR 7504), ISIS (UMR 7006), Université de Strasbourg and CNRS, 67000 Strasbourg, France

We theoretically characterize the semiclassical dynamics of an ensemble of atoms after a sudden quench across a driven-dissipative second-order phase transition. The atoms are driven by a laser and interact via conservative and dissipative long-range forces mediated by the photons of a single-mode cavity. These forces can cool the motion and, above a threshold value of the laser intensity, induce spatial ordering. We show that the relaxation dynamics following the quench exhibits a long prethermalizing behavior which is first dominated by coherent long-range forces and then by their interplay with dissipation. Remarkably, dissipation-assisted prethermalization is orders of magnitude longer than prethermalization due to the coherent dynamics. We show that it is associated with the creation of momentum-position correlations, which remain nonzero for even longer times than mean-field predicts. This implies that cavity cooling of an atomic ensemble into the self-organized phase can require longer time scales than the typical experimental duration. In general, these results demonstrate that noise and dissipation can substantially slow down the onset of thermalization in long-range interacting many-body systems.

Q 25.6 Tue 15:45 P 4

Atomic self-organization in multi-mode cavities — •Tim Keller[1], Simon B. Jäger[1], Stefan Schütz[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]icFRC, IPCMS (UMR 7504) and ISIS (UMR 7006), University of Strasbourg and CNRS, 67000 Strasbourg, France

We derive a semiclassical model for the out-of-equilibrium dynamics of laser driven atoms, which also interact with two high-Q crossed cavities as in [1]. In the semiclassical limit the dynamics of the atoms is governed by a Fokker-Planck equation (FPE) for the atomic Wigner function, which generalizes the FPE of [2]. We identify the conditions under which the stationary state of the system can exhibit (i) a paramagnetic phase, where there is no stationary intracavity field, (ii) a nematic phase where the intracavity field is of solely one of the two resonators, and (iii) a ferromagnetic phase where both cavities are populated. Each phase of the cavity field is accompanied by different atomic density distributions. We show that this system can be mapped to the Generalized Hamiltonian Mean Field model [3] and determine the phase diagram as a function of the laser parameters. We furthermore analyse the dynamics following sudden quenches across the various phases.

[1] J. Léonard et al., arXiv preprint arXiv:1609.09053 (2016).
[2] S. Schütz, H. Habibian, and G. Morigi, PRA 88, 033427 (2013).
[3] A. Pikovsky et al., Phys. Rev. E 90, 062141 (2014).

Q 25.7 Tue 16:00 P 4

Localization transition in presence of cavity backaction — Katharina Rojan[1,2,3], •Rebecca Kraus[1], Thomás Fogarty[1,4], Hessam Habibian[1], Anna Minguzzi[2,3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Université Grenoble-Alpes, LPMMC, BP166, F-38042 Grenoble, France — [3]CNRS, LPMMC, BP166, F-38042 Grenoble, France — [4]Quantum Systems Unit, OIST, Okinawa 904-0495, Japan

We study the localization transition of an atom confined by an external optical lattice in a high-finesse cavity. The atom-cavity coupling yields an effective secondary lattice potential, whose wavelength is incommensurate with the periodicity of the optical lattice. The cavity lattice can induce localization of the atomic wave function analogously to the Aubry-André localization transition. Starting from the master equation for the cavity and the atom we perform a mapping of the system dynamics to a Hubbard Hamiltonian, which can be reduced to the Harper's Hamiltonian in appropriate limits. We evaluate the phase diagram for the atom's ground state and show that the transition between extended and localized wave function is controlled by the strength of the cavity nonlinearity, which determines the size of the localized region and the behavior of the Lyapunov exponent. The Lyapunov exponent, in particular, exhibits resonancelike behavior in correspondence with the optomechanical resonances. We then analyse localization when this setup confines a gas of identical bosonic atoms, which solely interact via the cavity-mediated long-range forces.

Q 26: Quantum Optics IV

Time: Tuesday 14:30–16:00 Location: P 5

Q 26.1 Tue 14:30 P 5

Spectral intensity correlations of broadband amplified spontaneous emission from superluminescent diodes — •Patrick Janassek, Sébastien Blumenstein, and Wolfgang Elsässer — Institute of Applied Physics, Technische Universität Darmstadt, Germany

The intensity correlations of broadband light play an important role in understanding the physics of the emission processes. Photons emitted by thermal light sources show the well-known bunching effect which leads to a second-order coherence degree of $g^{(2)}(0) = 2$. However, the measurement of high-order coherence functions of broadband light sources such as superluminescent diodes (SLD) is particular challenging due to the very short correlation timescales. By exploiting two-photon-absorption (TPA) interferometry[1] the intensity correlations of the amplified spontaneous emission (ASE) from SLDs with THz-wide optical spectra can be measured. Here, we present experiments on varying spectral intensity correlations of SLD light. Within a TPA Mach-Zehnder interferometer configuration, intensity cross-correlation functions between different spectral components $g^{(2)}(\tau, \lambda)$ are determined. We observe a continuous reduction of the second-order coherence degree with increasing spectral separation of selected spectral windows measured by introducing variable bandpass filters in both arms of the interferometer. These observations suggest the existence of frequency correlations of bunched photons from ASE of SLDs.

[1] F. Boitier, A. Godard, E. Rosencher, and C. Fabre, Nat. Phys. 5, 267 (2009)

Q 26.2 Tue 14:45 P 5

Spectrally filtered photon pairs cannot be both pure and efficient — •Evan Meyer-Scott, Nicola Montaut, Linda Sansoni, Harald Herrmann, Tim J. Bartley, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Photon pairs from spontaneous parametric down conversion or four-wave mixing are widely employed in quantum cryptography, quantum computing, and fundamental physical tests. For photons from separate sources to interfere, for example for entanglement swapping, linear optical quantum computing, or quantum walks, the photons must be spectrally pure. This requires that the frequency of each photon in the pair be uncorrelated with the other's, which can be achieved by narrowband filtering each photon. Here we show that this filtering comes at a direct cost of heralding efficiency, the efficiency to detect one photon of the pair given a detection of the other. We find this effect is fundamental rather than technical, and independent of filter shape and filter, pump, and phasematching bandwidth, but can be eliminated by source engineering to bring the phasematching angle to a certain range. We support our analytical and numerical results with an experiment that directly shows the tradeoff between purity and heralding efficiency.

Q 26.3 Tue 15:00 P 5

Synchronization of Active Atomic Clocks via Quantum and Classical Channels — •Alexander Roth and Klemens Hammerer — Leibniz University Hannover

Superradiant lasers based on atomic ensembles exhibiting ultra-narrow optical transitions can emit light of unprecedented spectral purity and may serve as active atomic clocks. We consider two frequency-detuned active atomic clocks, which are coupled in a cascaded setup, i.e. as master & slave lasers, and study the synchronization of the slave to the master clock. In a setup where both atomic ensembles are coupled to a common cavity mode such synchronization phenomena have been predicted by Xu et al. [Phys. Rev. Lett. 113, 154101 (2014)] and experimentally observed by Weiner et al. [arXiv:1503.06464 (2015)]. Here we demonstrate that synchronization still occurs in cascaded setups but exhibits distinctly different phase diagrams. We study the characteristics of synchronization in comparison to the case of coupling through a common cavity. We also consider synchronization through a classical channel where light of the master laser is measured phase sensitively and the slave laser is injection locked by feedback and compare to the results achievable by coupling through quantum channels.

Q 26.4 Tue 15:15 P 5

Probing Nanofriction and Aubry-type signatures in a finite self-assembled system — •Jan Kiethe[1], Ramil Nigmatullin[2], Dimitri Kalincev[1], Thorben Schmirander[1], and Tanja Mehlstäubler[1] — [1]PTB, Braunschweig, Deutschland — [2]University of Sydney, Sydney, Australia

Ion traps are a versatile tool for a broad range of applications, such as quantum information and precision measurements. They offer a well-controlled experimental environment in which ions can be stored and manipulated. If the ions are cooled to energies lower than the potential energy of the Coulomb system, they form crystals, which can be used as quantum simulators and emulators for non-equilibrium statistical physics. A great advantage of trapped ion crystals is the in situ access to the dynamics of the particles, which are often not accessible in the emulated system. We mimic the boundary of two atomically flat solids with a self-assembled ion Coulomb crystal in the zigzag phase and study nanofriction between these back-acting ion chains. With the help of phonon mode spectroscopy and high resolution imaging we show that a structural defect causes a sticking-to-sliding transition with Aubry-type signatures. We observe the soft vibrational mode in the motional spectrum and symmetry-breaking in the crystal configuration. The corresponding order parameter and the soft mode frequency exhibit critical scaling near the transition. This model system can be used to investigate the tribological behaviour of self-organized structures in the classical and in the quantum regime.

Q 26.5 Tue 15:30 P 5

Photoluminescence excitation spectroscopy of SiV^- and GeV^- color center in diamond — •Stefan Häussler[1], Andreas Dietrich[1], Gergo Thiering[2], Junichi Isoya[3], Takayuki Iwasaki[4], Adam Gali[2], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Wigner Research Centre for Physics, Budapest, Hungary — [3]Research Center for Knowledge Communities, Tsukuba, Japan — [4]Tokyo Institute of Technology, Tokyo, Japan

Color centers in diamond and in particular the NV center have been proved to be good candidates for the realization of protocols for quantum information and quantum sensing. Recently the negatively

charged silicon-vacancy (SiV^-) and germanium-vacancy (GeV^-) defects have drawn attention due to their exceptional optical properties. For SiV^- a comparably large DW factor, a very small inhomogeneous line broadening and a large spectral stability has been demonstrated, facilitating efficient generation of indistinguishable photons. Understanding the electronic level structure is of fundamental interest for future quantum optics experiments based on the two color centers.
We present photoluminescence (PL) and excitation (PLE) measurements for both, an ensemble of negatively charged SiV and GeV centers at room temperature using a costum build confocal microscope. We measured PLE spectra over a broad wavelength range from 460 to 650 nm and performed saturation spectroscopy with high power density laser to investigate the electronic level structure of the two color centers comparing our results with in-depth theoretical simulations.

Q 26.6 Tue 15:45 P 5

Closed-loop optimization of single spin control in room-temperature solids — •Florian Frank[1], Thomas Unden[1], Ressa S. Said[2], Jonathan Zoller[2], Simone Montangero[2], Tomasso Calarco[2], Boris Naydenov[1], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Center for Integrated Quantum Science and Technology, Institute for Complex Quantum Systems, Ulm University, D-89081 Ulm, Germany

We show a closed-loop correction of electron spin dynamics associated with a single colour center in diamond at room-temperature.

Target spin state and process are examined by standard tomographic measurements and their performances against systematic errors are iteratively rectified by an optimal pulse engineering algorithm manifesting full potential for applications in quantum technologies.

Q 27: Nano-Optics III

Time: Tuesday 14:30–16:30 Location: P 11

Q 27.1 Tue 14:30 P 11

Real-time propagation of a Na_{297} dimer as a coupled Maxwell-Schrödinger and time-dependent Kohn-Sham-Maxwell system — •Rene Jestaedt[1,2], Heiko Appel[1,2], and Angel Rubio[1,2] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Max-Planck-Institut für Struktur und Dynamik der Materie, Hamburg, Germany

External electromagnetic fields can induce non-negligible electric currents which influence the total Maxwell fields inside molecular systems. This backreaction affects the conductivity and the optical properties of molecular and nanoplasmonic systems. In the present work, we employ the Riemann-Silberstein vector of the electromagnetic field to cast Maxwell's equations into a spinor representation similar to the Dirac equation [1]. This representation allows us to use standard unitary propagation techniques [2], both for Maxwell's equations and the time-dependent Kohn-Sham equations. To illustrate our novel implementation of the coupled Maxwell-Kohn-Sham equations in the real-space code octopus [3], we show the effects of a large matter feedback to the Maxwell fields and vice versa a radiation feedback to electrons and nuclei for a Na_{297} nanoparticle.

[1] I. Bialynicki-Birula, Progress in Optics **36**, 245-294, (1996).
[2] A. Castro et al., J. Chem. Phys. **121**, 3425-3433, (2004).
[3] X. Andrade et al., J. Phys. Cond. Mat. **24**, 233202, (2012).
[4] R. Jestädt et al., (submitted)

Q 27.2 Tue 14:45 P 11

100-fold Enhancement of Spontaneous Emission from a Single Quantum Dot by a Gold 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 of Erlangen-Nürnberg, Erlangen, Germany

Control and enhancement of spontaneous emission has been an intriguing and active topic of research in the past few decades. Previously, we have theoretically suggested that a plasmonic gold nanocone antenna is promising for achieving spontaneous emission enhancements exceeding 1000 while maintaining a high quantum efficiency [1]. Here, we report on first experiments corresponding to this concept. The gold nanocones were fabricated by focused ion beam milling on a glass substrate [2]. By positioning a single semiconductor quantum dot with nanometer accuracy in the near field of the nanocone antenna, we observed large lifetime reductions for both monoexciton and biexciton emission. By performing saturation studies and analysing the photon statistics, we determined the radiative decay rate enhancement of the monoexciton and biexciton emission to be 109 and 100 folds with quantum efficiencies of 60% and 70%, respectively [3]. Such large enhancements open the door to many applications in light emitting technologies and fundamental research. [1] X. Chen, M. Agio, and V. Sandoghdar, *Phys. Rev. Lett.* **108**, 233001 (2012). [2] B. Hoffmann *et al.*, *Nanotechnology* **26**, 404001 (2015). [3] K. Matsuzaki *et al.*, *arXiv.*:1608.07843 (2016).

Q 27.3 Tue 15:00 P 11

Coherent interaction between a single molecule and a plasmonic nanoantenna — •Johannes Zirkelbach[1], Benjamin Gmeiner[1], Tobias Utikal[1], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light (MPL), D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-University of Erlangen-Nürnberg, D-91058 Erlangen, Germany

We report on the coherent interaction of light with a coupled system consisting of a single quantum emitter and a plasmonic nanostructure. Here, we combine cryogenic high-resolution spectroscopy with localization microscopy to study single molecules in the vicinity of isolated plasmonic nanostructures embedded in a thin organic matrix. We discuss the spectral and spatial behavior of the extinction spectra recorded from the composite molecule-antenna system, leading to Fano profiles in the far-field interference signal. Future experiments will aim to observe transparency (cloaking) and ultrastrong absorption [1].

[1] X. Chen, V. Sandoghdar, and M. Agio, Phys. Rev. Lett. 110, 153605 (2013)

Q 27.4 Tue 15:15 P 11

Exceptional mode organization in a resonator microcavity based on a hyperbolic metamaterial — •Evgenij Travkin, Sascha Kalusniak, Sergey Sadofev, and Oliver Benson — Humboldt-Universität zu Berlin, Institut für Physik, Newtonstraße 15, 12489 Berlin

Metamaterials offer a variety of exciting possibilities for manipulation of light among which are i.e. the control of phase and group velocity and negative refraction. We investigate a hyperbolic metamaterial (HMM) based on stacked layer pairs of epitactically grown ZnO/ZnO:Ga embedded in a resonator microcavity. The highly anisotropic and frequency dependent HMM refractive index enables a unique distribution of resonant modes. Several modes of the same order can exist at different frequencies and the relative spectral positions of higher and lower order modes can interchange resulting in an anomalous mode organization. We present experimental spectra demonstrating unconventional mode emergence and reversal of the mode order in differently scaled HMM-based cavities and supplement them by transfer matrix calculations and dispersion relations derived from the cavity roundtrip condition. Our system can be fully tailored by tuning of the layer thickness ratio and doping level of the HMM.

Q 27.5 Tue 15:30 P 11

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 radius of curvature of 5 μm fabricated with focused ion-beam milling and coated with silver. By integrating an organic matrix in the microcavity at liquid helium temperature, we are able to coherently couple individual molecules to the single mode of the cavity. Our results show that a single molecule can attenuate 38% of the light stored in the cavity. We also demonstrate four-fold improvement of single-molecule stimulated emission compared to free-space coupling in a tight focus. Our experimental approach based on a microcavity with low mode volume and low quality factor paves the way for the realization of a series of nonlinear and collective quantum optical effects.

Q 27.6 Tue 15:45 P 11

Extreme single-emitter interaction with two-coupled bad resonators — •Burak Gurlek, Vahid Sandoghdar, and Diego Martin-Cano — Nano-Optics Division, Max Planck Institute for the Science of Light, Erlangen, Germany.

Nonlinear photon generations require strong interactions between light and matter. Nanoantennas and optical cavities are two complimentary and common approaches for enhancing these interactions at extreme levels, the first relying on extremely small volumes whereas the second on small bandwidths (high Q-factors). Recently, it has been proposed that hybrid combinations between nanoantenna and a high Q cavity can further enhance the spontaneous emission of a single quantum emitter [1, 2]. Here, we explore a hybrid system based on a low-Q cavity and a nanoantenna, leading to non-intuitive additional enhancements and quenching behavior. Taking a confocal cavity and a nanocone as an example, we make use of the Quasi Normal Mode (QNM) approach [3] to study the interference mechanism that creates these interesting properties. Our results provide new possibilities for improving the efficiency of single emitters and entering extreme regimes of photophysics. References: [1] Y. Xiao et al., Phys. Rev. A 85, 031805(R) (2012). [2] H. M. Doeleman et al., ACS Photonics 3 (10), 1943-1951 (2016). [3] C. Sauvan et al., PRL 110, 237401 (2013).

Q 27.7 Tue 16:00 P 11

Strong coupling between surface plasmon polaritons and molecular vibrations — •Hala Memmi, Sascha Kalusniak, Sergey Sadofev, and Oliver Benson — Institut für Physik, Humboldt Universität zu Berlin

The hybridization of different quasi-particles is an extensively studied subject; both from a practical as well as fundamental point of view. The resultant hybrid excitations exhibit new properties that are not available by the isolated constituents.

Here, we report on hybridization of surface plasmon polaritons and molecular vibrations in an organic/inorganic plasmonic hybrid structure. The structure consists of a poly-vinyl-methyl-ketone layer deposited on top of a silver layer. Attenuated-total-reflection measurements allow us to reconstruct the dispersion relation of the hybrid. The system exhibits two polariton branches clearly demonstrating anticrossing behavior in vicinity of the carbonyl stretching vibration of the polymer with the coupling strength of 14 meV. Systematic tuning of the carbonyl group density confirms the square root dependence of the energy splitting. We also present some of the characteristics of this hybrid species and discuss its potential applications.

Q 27.8 Tue 16:15 P 11

Attosecond time-resolved photoelectron spectroscopy of hybridnanoresonators — Julia Hengster and •Thorsten Uphues — CFEL, Attosecond Research and Science Group, Hamburg University, Luruper Chaussee 149, 22761 Hamburg

Understanding plasmons as collective oscillations of the free-electron gas density important questions related to their propagation, damping, charge and energy localization came up. Nevertheless the behaviour of hybrid nanostructures approaching the monolayer limit raises a new type of questions concerning their plasmonic behaviour in space and time, following the complex dynamics of the electromagnetic field. Attosecond time-resolved experiments are on the way to resolve subcycle electron dynamics from plasmonic interaction of ultrashort driving pulses in surfaces and nanostructures. Our approach of attosecond photoscopy demonstrates a reliable route to extend attosecond technology to surface and nanostructure dynamics. Hybrid nanostructures exhibit complex plasmonic properties sensitive to parameters as geometrical aspect ratios or material compositions. Vertically aligned disk nano-resonators belong to a group of tailored systems demonstrating field enhancement with strong localization. We found a remarkably sensitive behaviour in the coupling of surface and bulk plasmons of the resonators with ultrafast subcycle dynamics. As a proof-of-concept we demonstrate attostreaking from gold films with significant deviation to gas-phase streaking. Furthermore we developed non-destructive preparation procedures for nanoparticle samples as a basic requirement for attosecond photoscopy.

Q 28: Precision Measurements and Metrology: Interferometry II

Time: Tuesday 14:30–16:45 Location: P 104

Q 28.1 Tue 14:30 P 104

Theoretical study of Bose-Einstein condensates in optical 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

Highly sensitive atom interferometers require the two interferometer arms to enclose a large area in spacetime.

In parallel to the implementation of large interrogation times in microgravity [1] and fountains [2], a larger spatial separation with large momentum transfer (LMT) enhances the sensitivity of atomic sensors. A promising method to realize these novel schemes is to combine Bragg pulses and Bloch oscillations in optical lattices to coherently split and recombine the atomic wave packets. However, the finite momentum width of the atomic ensemble or the damping of Bloch oscillations due to tunneling constrain the fidelity of the LMT.

We theoretically analyze the coherent acceleration of BECs in 1D optical lattices to understand and optimize pioneering experiments performed in the QUANTUS collaboration. To this end, a 1D-reduced Gross-Pitaevskii model [3] is adapted to interpret and propose realistic novel LMT schemes.

[1] H. Müntinga et al. Phys. Rev. Lett. 110, 093602 (2013)
[2] S. M. Dickerson et al. Phys. Rev. Lett. 111, 083001 (2013)
[3] L. Salasnich et al. Phys. Rev. A 66, 043613 (2002)

Q 28.2 Tue 14:45 P 104

Fast BEC transport with atoms chips for inertial sensing — •Robin Corgier[1], Sirine Amri[2], Eric Charron[2], Ernst Maria Rasel[1], and Naceur Gaaloul[1] — [1]Leibniz University of Hanover, Germany — [2]Université Paris-Sud, France

Recent proposals in the field of fundamental tests of foundations of physics assume Bose-Einstein condensates (BEC) as sources of atom interferometry sensors. Atom chip devices have allowed to build transportable BEC machines with high repetition rates as demonstrated in the QUANTUS project. The proximity of the atoms to the chip surface is, however, limiting the optical access and the available interferometry time necessary for precision measurements. In this context, a fast and perturbation-free transport of the atoms is required. Shortcuts to adiabaticity protocols were proposed and allow in principle to implement such sequences with well defined boundary conditions. In this theoretical study, one can engineer suitable protocols to move atomic ensembles trapped at the vicinity of an atom chip by tuning the values of the realistic chip currents and external magnetic fields. Experimentally applicable trajectories of the atomic trap optimizing the transport time and reducing detrimental effects due to the offset of atoms positions from the trap center are found using a reverse engineering method. We generalize the method in order to optimize the size evolution and the center of a BEC wave packet in phase space. This allows an efficient delta-kick collimation to the pK level as observed in the Quantus 2 experiment. With such low expansion rates, atom interferometry experiments with seconds of drift time are possible.

Q 28.3 Tue 15:00 P 104

Symmetric scalable large momentum transfer beam splitter — •Martina Gebbe[1], Sven Abend[2], Matthias Gersemann[2], Hauke Müntinga[1], Holger Ahlers[2], Wolfgang Ertmer[2], 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 Quantenoptik, Uni Ulm — [5]Institut für angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Due to their small spatial and momentum width ultracold Bose-Einstein condensates (BEC) or even delta-kick collimated (DKC) atomic ensembles are very well suited for high precision atom interferometry. We generate such an ensemble in a miniaturized atom-chip setup where BEC generation and delta-kick collimation can be performed in a fast and reliable way. We present a symmetric double Bragg diffraction technique offering interesting new features for atom interferometry. The coherent manipulation is directed along the horizontal axis and combined with Bloch oscillations in order to realize symmetric scalable large momentum beam splitters. We employ this new type of beam splitter to study the performance of scalable Mach-Zehnder interferometers whose sensitivity increases linearly with velocity separation. 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 numbers DLR 50WM1552-1557 (QUANTUS-IV-Fallturm).

Q 28.4 Tue 15:15 P 104

A sensitive electrometer based on a Rydberg atom in a Schrödinger-cat state — •Eva-Katharina Dietsche, Arthur Larrouy, Adrien Facon, Serge Haroche, Jean-Michel Raimond, Michel Brune, and Sebastien Gleyzes — Laboratoire Kastler Brossel, College de France, ENS-PSL, UPMC-Sorbonne Universite, CNRS, Paris France

The Rydberg atoms are highly excited states where the electron is orbiting far from the nucleus. As a result, they have a huge electric dipole, making them ideal probes of the electric field. Rydberg states are highly degenerated. However, in the presence of a small electric field, this degeneracy is lifted and it is possible to drive transitions between the different Stark sublevels by applying radiofrequency fields. It is then possible to manipulate the state of the atom inside the manifold. We have recently shown that by using a radiofrequency field with a well-defined polarization it is possible to restrict the evolution of the atom to a subspace of the manifold where it behaves like a large angular momentum J. We have prepared non-classical states, similar to Schrödinger cat states, that allowed us to measure small variations of the electric field with a sensitivity beyond the standard quantum limit [1]. We are now investigating more complex manipulations of the atom to take advantage of the full richness of the Rydberg manifold. By using a combination of radiofrequency fields of different polarizations we can explore a larger part of the level structure. This opens the way to schemes that give access to higher moments of the electric field.

[1] A. Facon et al. Nature 535, 262-265 (2016)

Q 28.5 Tue 15:30 P 104

Using Schrödinger cat states of Rydberg atoms to measure fast electric fields — •Eva-Katharina Dietsche, Arthur Larrouy, Adrien Facon, Serge Haroche, Jean-Michel Raimond, Michel Brune, and Sebastien Gleyzes — Laboratoire Kastler Brossel, College de France, ENS-PSL, UPMC-Sorbonne Universite, CNRS, Paris France

We present a quantum-enabled measurement of the electric field using Rydberg atoms. We prepare the atom in a quantum superposition of two circular states with principle quantum number n=50 and n=51. Using a radiofrequency field resonant with the Stark transition in the n=50 manifold we transfer the n=50 part of the wave function from its horizontal circular orbit to a tilted elliptical trajectory. This creates a Schrödinger cat superposition of two states with very different polarizabilities whose relative phase is highly sensitive to variations in the amplitude of the electric field. Detecting this phase change using Ramsey interferometry allows us to measure the electric field with a precision below the standard quantum limit (SQL) [1]. This allows using the Rydberg atom as a microscopic electrometer that can perform time-resolved field measurements with a very high bandwidth.

[1] A. Facon et al. Nature 535, 262-265 (2016)

Q 28.6 Tue 15:45 P 104

Fock state metrology — •Fabian Wolf[1], Chunyan Shi[1], Jan Christoph Heip[1], Marius Schulte[3], Klemens Hammerer[3], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität, 30167 Hannover, Germany — [3]Institute for Theoretical Physics, Leibniz Universität, 30167 Hannover, Germany

The field of quantum metrology promises measurements with unprecedented accuracies and sensitivities using non-classical states. The idea behind quantum metrology is to prepare the investigated system or the measurement probe in a quantum states to reduce certain types of noise. In particular shot noise or quantum projection noise represents the major limitation for stability in state-of-the-art precision experiments ranging from gravitational wave detection to optical atomic clocks. The most prominent examples for states with non-classical features, previously investigated for this purpose are Schrödinger cat states and squeezed states and metrological gain compared to classical states has been demonstrated. Recently, investigations started to focus on the properties of states with negative Wigner function. However, so far the metrological gain of these states has not been verified experimentally. Here, we demonstrate that force measurements on an ion, trapped in a linear Paul trap can beat the classical limit, if the ion is initially prepared in a motional Fock state. Our scheme does not include any entanglement or squeezing and therefore illustrates the power of quantum interference due to negative Wigner functions for quantum metrology.

Q 28.7 Tue 16:00 P 104

Phase magnification for robust atom interferometry beyond the SQL — •Fabian Anders — Institut für Quantenoptik, LUH Hannover, Deutschland

The two-axis counter-twisting interaction provides the possibility for detection noise robust atom interferometry beyond the standard quantum limit. Our scheme complements recent approaches based on one-axis twisting to magnify the interferometric phase.

In both concepts, the non-linear interaction is not only applied before the interferometer to generate entanglement, but also afterwards to amplify the signal. We compare both squeezing-echo approaches in their optimal performance as well as for experimentally feasible parameters. We find that varying the echo strength can further improve the robustness against detection noise. We obtain simple analytical results for the one-mode approximation of the scheme. Additionally, we investigate spin dynamics in a spinor condensate as suitable interaction to effectively implement this technique.

Q 28.8 Tue 16:15 P 104

Random bosonic states for robust quantum metrology — Michał Oszmaniec[1], Remigiusz Augusiak[1,2], •Christian Gogolin[1,3], Janek Kołodyński[1], Antonio Acín[1,4], and Maciej Lewenstein[1,4] — [1]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]Center for Theoretical Physics, Polish Academy of Sciences, Aleja Lotników 32/46, 02-668 Warsaw, Poland — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [4]ICREA-Institució Catalana de Recerca i Estudis Avançats, Lluis Companys 23, 08010 Barcelona, Spain

We study how useful random states are for quantum metrology, i.e., whether they surpass the classical limits imposed on precision in the canonical phase estimation scenario. We prove that random pure states drawn from the Hilbert space of distinguishable particles typically do not lead to super-classical scaling of precision. Conversely, we show that random states from the symmetric subspace typically achieve the optimal Heisenberg scaling. Surprisingly, the Heisenberg scaling is observed for states of arbitrarily low purity and preserved under the loss of fixed number of particles. Moreover, we prove that for such states a standard photon-counting interferometric measurement suffices to typically achieve the Heisenberg scaling of precision for all values of the phase at the same time. Finally, we demonstrate that metrologically useful states can be prepared with short random optical circuits.

Q 28.9 Tue 16:30 P 104

The First Sounding Rocket Flight with an Atom Interferometer — •Stephan T. Seidel[1], Maike D. Lachmann[1], Dennis Becker[1], Wolfgang Ertmer[1], Ernst M. Rasel[1], and QUANTUS Collaboration[2] — [1]Institut für Quantenoptik, Universität Hannover — [2]LU Hannover, U Bremen, JGU Mainz, U Hamburg, HU Berlin, FBH, TU Darmstadt, U Ulm

The possibility of precise measurements of inertial forces using atom interferometry has led to a multitude of proposals for future satellite missions. These include missions aimed at geodetic measurements like a characterization of earth's gravitational field gradient and fundamental physics like a test of the universality of free fall.

Current ground based experiments are not suitable for the use on a satellite mission and a series of new technological and experimental techniques are required. This creates the necessity for pathfinder missions to test atom interferometer setups in relevant environments. To bridge this gap three sounding rocket missions are currently being prepared. The launch of the first mission is aimed at both the first creation of Bose-Einstein Condensates (BEC) and first demonstration of light atom interferometry in space.

Its payload can create BECs of 10^5 atoms from ^{87}Rb within two seconds. Therefore 70 experiments can be performed within the microgravity time including an observation of the phase transition and the characterization of the BECs after long free evolution times using atom interferometry. The system was qualified for the flight in a series of vibration tests and is currently in wait for favorable wind conditions.

Q 29: Quantum Gases: Bosons IV

Time: Tuesday 14:30–16:45 Location: P 204

Q 29.1 Tue 14:30 P 204

Non-equilibrium condensation of weakly interacting bosons in the presence of thermal baths: treating temperature-dependent dissipation — •Alexander Schnell and André Eckardt — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

When a quantum system is coupled weakly to a rapidly relaxing thermal bath of inverse temperature β, 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, whose rates depend the bath temperature through the product $\beta\Delta E$ involving the energy change ΔE. Taking into account this form of temperature-dependent dissipation for a many-body system far from equilibrium 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 and apply it to describe non-equilibrium Bose condensation in weakly interacting Bose gases in contact with two thermal baths of different temperature.

Q 29.2 Tue 14:45 P 204

Center of mass dynamics across the superfluid to Mott insulator phase transition in an optical lattice. — •Andreas Müllers[1], Christian Baals[1,5], Bodhaditya Santra[1,3], Ralf Labouvie[1,5], Thomas Mertz[2], Arya Dhar[2], Ivana Vasic[4], Agnieszka Cichy[2], Walter Hofstetter[2], and Herwig Ott[1] — [1]Research Center OPTIMAS and Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Institut für Theoretische Physik, Goethe-Universität Frankfurt, D-60438 Frankfurt/Main, Germany — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [4]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, 11080 Belgrade, Serbia — [5]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany

We study the relaxation dynamics of a many-body quantum system after forcing it out of equilibrium by displacing an underlying potential. We adiabatically load ^{87}Rb atoms into a 3D optical lattice superimposed on an optical dipole trap and then shift the trapping potential by $1\,\mu$m. Using a scanning electron microscope, we image the center of mass motion of the atoms during relaxation for various depths of the optical lattice, spanning the superfluid to Mott-insulator phase transition. We observe varying dynamics across the transition and by piecewise analysis of the system, we can also identify a thermal phase at the edges which moves with velocities in between those of the superfluid and the insulating phase. We present our measured data and the results of theoretical modeling currently in progress.

Q 29.3 Tue 15:00 P 204

Density ordering dynamics at an insulator to insulator transition — •Lorenz Hruby, Nishant Dogra, Katrin Kröger, Manuele Landini, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Engineering of open quantum many-body systems allows for new insights into the dynamics of complex quantum phases. Here we experimentally explore the phase transition between two insulating phases of Mott type with different density ordering. The transition is driven by competing on-site and global-range interactions. We monitor the temporal dynamics of the density order parameter in real-time and we observe a hysteresis loop and the emergence of two distinct timescales in the ordering dynamics. We explain our findings using a mean-field approach featuring metastable many-body states. Our system is based on a Bose-Einstein condensate trapped in a three-dimensional optical lattice which controls the on-site interaction strength. Tunable atom-atom interactions of global-range are mediated by coupling the condensate to a single mode of an optical cavity.

Q 29.4 Tue 15:15 P 204

Models for a multimode bosonic tunneling junction — •David Fischer[1] and Sandro Wimberger[1,2,3] — [1]Institut für Theoretische Physik, Philosophenweg 12, Universität Heidelberg, 69120 Heidelberg, Germany — [2]Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università degli Studi di Parma, Parco Area delle Scienze 7/a, 43124 Parma, Italy — [3]INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma,Italy

We discuss the relaxation dynamics for a bosonic tunneling junction with two modes in the central potential well. We use a master equation description for ultracold bosons tunneling into two central modes in the presence of noise and incoherent coupling processes. The master equation is solved exactly with quantum jump simulations. Whilst we cannot quantitatively reproduce the experimental data of the setup reported in [1], we find a reasonable qualitative agreement of the refilling process of the initially depleted central site. Furthermore an analysis of the time scale of the refilling shows a power-law behavior with respect to the decoherence rates, with *similar exponents* for all analyzed processes. Our results may pave the way for the control of bosonic tunneling junctions by the simultaneous presence of decoherence processes and atom-atom interaction.

[1] R. Labouvie, B. Santra, S. Heun, S. Wimberger, and H. Ott, Phys. Rev. Lett. **115**, 050601 (2015).

Q 29.5 Tue 15:30 P 204

A Bosonic Josephson Junction with an Impurity — •Maximilian Dirkmann, Gabriel Dufour, and Andreas Buchleitner — Institute of Physics, University of Freiburg, Germany

We study the dynamics of a Bose-Einstein condensate in a double-well potential, or bosonic Josephson junction [1], in the presence of a mobile impurity particle. This allows us to test the practicability of a quantum probe scheme, where measurements are performed on the impurity in order to obtain information about the rest of the system.

The system is described using a two-site Bose-Hubbard Hamiltonian which accounts for tunneling between the wells and on-site interactions between the particles. We observe a variety of dynamical regimes as the relative strength of tunneling and interactions is changed. In particular, we study the entanglement of the impurity particle with the rest of the system. In the weakly interacting regime, we demonstrate that the amplitude of impurity's oscillations between the two wells is related to the purity of its reduced density matrix.

[1] G.J. Milburn et al. *Phys. Rev. A* **55**, 4318-4324 (1997).

Q 29.6 Tue 15:45 P 204

A path-integral approach to composite, rotating impurities — •Giacomo Bighin and Mikhail Lemeshko — Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria

The study of composite, rotating impurities interacting with a quantum many-body environment is extremely important for 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. In all these cases the vibrational and rotational degrees of freedom create an involved energy level structure, with a continuous exchange of angular momentum with the surrounding environment. The recently-introduced angulon quasiparticle [1] formalises the concept of a rotating, interacting impurity. In this talk we introduce an alternative approach to the angulon problem making use of the path integral formalism, extending Feynman's treatment for the polaron. A clear advantage is that the bath degrees of freedom and the interaction can be integrated out exactly, resulting in an effective, single-particle description for the angulon in which the many-body character of the original problem is encoded in an interaction term. This alternative, effective treatment for the angulon is, in principle, valid at arbitrary coupling and at arbitrary temperature. The results obtained will be compared with existing state-of-the-art theories for composite impurities and with experimental data from the rotational spectrum of molecules embedded in helium nanodroplets.

References: [1] R. Schmidt and M. Lemeshko, Phys. Rev. Lett. 114, 203001 (2015) and Phys. Rev. X 6, 011012 (2016).

Q 29.7 Tue 16:00 P 204

Anomalous screening of quantum impurities by a neutral environment — •Enderalp Yakaboylu and Mikhail Lemeshko — Institute of Science and Technology Austria (IST Austria), Klosterneuburg, Austria

We investigate the dynamics of a rotating impurity interacting with a neutral many-body bosonic bath in the presence of an oscillating electric field. Even though light cannot interact with the neutral bath, we show that the neutral bath itself is capable to induce a drastic screening of the impurity's dipole moment and polarizability due to angular momentum transfer between the impurity and the bath. Consequently, all phenomena related to the light-molecule interaction can be generalized to the interaction in the presence of a neutral many-body environment by means of the screened dipole moment and the screened polarizability of the impurity. In particular, we showed how a neutral many-body environment affects the effective Rabi frequency, the geometric phase, and the molecular alignment.

Q 29.8 Tue 16:15 P 204

Dimensionally Induced Phase Transition of the Weakly Interacting Ultracold Bose Gas — •Bernhard Irsigler[1,2] and Axel Pelster[3] — [1]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, Germany — [2]Institut für Theoretische Physik, Freie Universität Berlin, Germany — [3]Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

We investigate the dimensionally induced phase transition from the normal to the Bose-Einstein condensed phase for a weakly interacting Bose gas in optical lattices. To this end we make use of the Hartree-Fock-Bogoliubov-Popov theory, where we include numerically exact hopping energies and effective interaction strengths. At first we determine the critical chemical potential, where we find a much better agreement with recent experimental data than a pure Hartree-Fock treatment [1]. We ascribe this finding to the dominant role of quantum fluctuations in lower dimensions. Furthermore, we determine for the 1D-3D-transition the power-law exponent of the critical temperature for two different non-interacting Bose gas models yielding the same exponent of 1/2 which indicates that they belong to the same universality class. For the weakly interacting Bose gas we find for both models that this exponent is robust with respect to finite interaction strengths.

[1] A. Vogler, R. Labouvie, G. Barontini, S. Eggert, V. Guarrera, and H. Ott, Phys. Rev. Lett. **113**, 215301 (2014)

Q 29.9 Tue 16:30 P 204

Observing the Goldstone and the amplitude mode in a supersolid quantum gas — •Julian Léonard, Andrea Morales, Philip Zupancic, Tilman Esslinger, and Tobias Donner — Institute for Quantum Electronics, ETH Zurich, Switzerland

A phase transition with continuous symmetry breaking of a scalar quantum field can give rise to excitations of its phase and amplitude. A supersolid presents an intriguing example for such an excitation spectrum, as both continuous gauge symmetry of the superfluid phase and the translational symmetry of the lattice modulation are broken simultaneously.

We investigate the interplay of these symmetries by studying the elementary excitations across the superfluid-supersolid phase transition. The supersolid phase is realized by coupling a Bose-Einstein condensate with the fields of two crossed cavity modes. We perform cavity-enhanced Bragg spectroscopy on the quantum gas to measure its excitation spectrum. In the superfluid phase, we observe two independent modes that soften upon approaching the critical point. Inside the supersolid phase the modes split into a low-energetic Goldstone mode and a high-energy amplitude mode.

Q 30: Ultracold atoms and BEC - III (with A)

Time: Tuesday 14:30–16:30 Location: N 1

Q 30.1 Tue 14:30 N 1

Efimov physics in ultracold atomic gases using finite-range potentials — •Thomas Secker, Paul Mestrom, and Servaas Kokkelmans — Eindhoven University of Technology, Eindhoven, The Netherlands

Three-body Efimov physics is relevant for the understanding of both dynamics and stability of ultracold gases. Efimov predicted the existence of an infinite sequence of three-body bound states, of which many properties scale universally, at diverging scattering length for a zero-range interaction potential. Experiments with ultracold atoms in which the scattering length is tuned through Feshbach resonances have also shown the universality of the negative three-body parameter. In order to investigate these universal aspects, we utilize a finite range interaction potential. We solve for this problem in a momentum-space treatment containing off-shell two-body scattering processes. To include the Feshbach formalism we have generalized it to an off-shell theory. First results show remarkable similarities with experimental data, especially in the case of broad resonances.

Q 30.2 Tue 14:45 N 1

Novel states in a three-body system with a p-wave resonance — •Matthias Zimmermann[1], Santiago I. Betelu[2], Maxim A. Efremov[1], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89081 Ulm, Germany — [2]Department of Mathematics, University of North Texas, Denton, TX 76203-5017, USA

One of the most intriguing phenomena of few-body physics is the Efimov effect, which manifests itself in an infinite number of weakly bound three-body states if at least two of the three two-body subsystems exhibit a single s-wave resonance.

We present a novel class of purely quantum-mechanical bound states in the system of three particles in two dimensions provided: (i) the system consists of a light particle and two heavy bosonic ones, and (ii) the heavy-light short-range potential has a p-wave resonance. Within the familiar Born-Oppenheimer approach, the effective potential between the two heavy particles is shown to be attractive and of long-range, resulting in an infinite number of universal bound states corresponding to a vanishing total angular momentum of the three-body system.

In order to verify our analytical results we employ a numerical scheme utilizing spectral methods. This enables us to discretize the stationary Schrödinger equation in function space in order to achieve exponential convergence. We solve the resulting eigenvalue problem with the Data Vortex supercomputing system.

Q 30.3 Tue 15:00 N 1

Impurities immersed in a BEC. Quantum simulator of the polaron? — •Luis Aldemar Ardila[1], Thomas Pohl[1], and Stefano Giorgini[2] — [1]Nöthnitzer Straße 38 01187 Dresden Germany — [2]Via Sommarive 14 I-38123 Povo, Italy

We investigate the properties of an impurity immersed in a Bose gas at zero temperature using both analytical and Quantum-Monte Carlo methods. The interaction between bosons are modeled by a hard-sphere potential with scattering length a, whereas the impurity-boson interaction is modeled by a short-range attractive square-well potential, where both the sign and the strength of the scattering length b can varied by adjusting the well depth. We characterize the repulsive and attractive [Fig. 1] polaron branch by calculating the binding energy and the effective mass [1]. Furthermore, we study the structure of the bosonic bath such as the boson-boson correlation function and the density profile around the impurity. For resonant interactions between the impurity and the bosonic bath, the Ground state properties are also investigated as well as Efimov Effects . The implication for the phase diagram of binary Bose-Bose mixtures is also discussed . We also discuss more complicated interactions between the impurity and the bosonic bath. For this case we consider a Quasi-2D Dipolar Bose gas at zero temperature. Furthermore, the impurity-Bose interaction is dipolar. Using perturbation theory, the Ground-state properties are investigated based on the low-energy Fröhlich Hamiltonian.

Q 30.4 Tue 15:15 N 1

The Bose polaron in an ultracold Bose-Fermi mixture of Cs and Li — •Stephan Häfner, Binh Tran, Manuel Gerken, Melina Filzinger, Bing Zhu, Juris Ulmanis, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

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 repulsive and attractive polarons. The observation of different polaron states, ranging from the Landau-Pekar polaron to the bubble polaron is within reach for the Li-Cs system.

In this talk we describe the production of a Cs BEC by forced evaporative cooling in an optical dipole trap. The phase-space density is enhanced by modifying the trapping geometry with an additional small-sized dipole trap. This is the first step for the study of the Bose polaron in the Li-Cs system.

Q 30.5 Tue 15:30 N 1

Observation of individual tracer atoms in an ultracold dilute gas — •Felix Schmidt[1,2], Daniel Mayer[1,2], Tobias Lausch[1], Daniel Adam[1], Steve Haupt[1], Michael Hohmann[1], Farina Kindermann[1], Nicolas Spethmann[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern

Diffusion of particles in fluids and gases is an essential and omnipresent transport phenomenon in nature. While diffusion is well understood in the limit of a heavy particle in a dense gas (known as Brownian motion), much less is known, both theoretically and experimentally, about light particles diffusing in a dilute gas.

Here, we report on the experimental investigation of individual Cs atoms impinging on a dilute cloud of ultracold Rb atoms with variable density. We study the nonequilibrium relaxation of the initial nonthermal state of Cs and detect the effect of a of single collision, i.e. the fundamental building block of diffusion. We show that the diffusive motion of the single Cs atom in the Rb cloud is well described by a generalized Langevin equation with a velocity-dependent friction coefficient, an unfamiliar feature of the Langevin equation emerging for light particles.

Q 30.6 Tue 15:45 N 1

angular self-localization of impurities rotating in a bosonic bath — •xiang li, mikhail Lemeshko, and robert seiringer — Institute of Science and Technology Austria, Am Campus 1, Klosterneuburg, Austria

The existence of a self-localization transition in the polaron problem has been under an active debate ever since Landau suggested it in 1933. Here we reveal the self-localization transition for the rotational analogue of the polaron - the angulon quasiparticle. The transition takes place at finite coupling strength already at the mean-field level, it is accompanied by a discontinuity in the first derivative of the angulon ground-state energy and a spherical-symmetry breaking of the angulon ground state. This symmetry breaking is demonstrated to be depend on the symmetry of the microscopic impurity-atom potential, which results in a number of distinct self-localized states. The predicted effects can potentially be addressed in experiments on cold molecules trapped in superfluid helium droplets and ultracold quantum gases, as well as on electronic excitations in solids and Bose-Einstein condensates.

[1] X. Li, R. Seiringer, M. Lemeshko, arXiv: 1610.04908

Q 30.7 Tue 16:00 N 1

Rotation of cold molecular ions inside a Bose-Einstein condensate — •Bikashkali Midya[1], Michal Tomza[2], Richard Schmidt[3], and Mikhail Lemeshko[1] — [1]Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria — [2]ICFO- The Barcelona Ins titute of Science and Technology, Barcelona, Spain — [3]ITAMP, Havard-Smithsonian Center for Astrophysics, Cambr idge, MA 02138, USA

We use recently developed angulon theory [1] to study the rotational spectrum of a cyanide molecular anion immersed into Bose-Einstein condensates of rubidium and strontium. Based on *ab initio* potential energy surfaces, we provide a detailed study of the rotational Lamb shift and many-body-induced fine structure which arise due to dressing of molecular rotation by a field of phonon excitations. We demonstrate that the magnitude of these effects is large enough in order to be observed in modern experiments on cold molecular ions. Furthermore, we introduce a novel method to construct pseudopotentials starting from the *ab initio* potential energy surfaces, which provides a means to obtain effective coupling constants for low-energy polaron models.

[1] R. Schmidt and M. Lemeshko, Phys. Rev. Lett. 114, 203001 (2015).

[2] B. Midya, M. Tomza, R. Schmidt, M. Lemeshko, Phys. Rev. A 94, 041601(R) (2016).

Q 30.8 Tue 16:15 N 1

Numerical Simulation of a mobile Impurity in a BEC — •Tobias Lausch[1], Fabian Grusdt[3], Artur Widera[1,2], and Michael Fleischhauer[1] — [1]TU Kaiserslautern and Forschungszentrum OPTIMAS, Erwin-Schroedinger-Strasse 46, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler Strasse 47, 67663 Kaiserslautern, Germany — [3]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Cooling atoms to ultracold temperatures, where quantum effects dominante, has become a standard approach in experimental quantum physics. An intriguing focus of research lies on impurity systems, aiming on elucidating microscopic properties of thermalization or quasiparticle formation in quantum systems. Recent experiments(1,2) shed light on the bose polaron and the interaction between impurities and a bose gas. We thoretically model the thermalization dynamics of a single impurity immersed into a BEC using Bogoliubov approximation. From the master equation, we derive the impurity's momentum resolved scattering and numerically simulate the ensuing cooling dynamics. We find a separation of relaxation time scales originating from the superfluid nature of the condensate, indicating a prethermalized state. Furthermore we discuss the possibuility to exploit the emerging non-thermal impurity states to realize low-entropy quantum states by applying external forces.

(1) Hu et al. PRL 117(2016), 055301

(2) Jørgensen et al. PRL 117 (2016), 055302

Q 31: Poster: Quantum Optics and Photonics I

Time: Tuesday 17:00–19:00 Location: P OGs

Q 31.1 Tue 17:00 P OGs

Observation of Four-body Ring-exchange Interaction and Anyonic Fractional Statistics — •Han-Ning Dai[1,2,3], Bing Yang[1,2,3], Andreas Reingruber[2,5], Hui Sun[1,3], Xiao-Fan Xu[2], Yu-Ao Chen[1,3,4], Zhen-Sheng Yuan[1,2,3,4], and Jian-Wei Pan[1,2,3,4] — [1]Hefei National Laboratory for Physical Science at Microscal and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [2]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [3]CAS Center for Excellence and Synergetic Innovation Center in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui, 230026, China — [4]CAS-Alibaba Quantum Computing Laboratory, Shanghai 201315, China — [5]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schroedinger-Strasse, Building 46, 67663 Kaiserslautern, Germany

We report the observation of four-body ring-exchange interactions and the topological properties of anyonic excitations within an ultracold atom system. A minimum toric code Hamiltonian in which the ring exchange is the dominant term, was implemented by engineering a Hubbard Hamiltonian that describes atomic spins in disconnected plaquette arrays formed by two orthogonal superlattices.

Q 31.2 Tue 17:00 P OGs

Observation of Quantum Criticality and Luttinger Liquid in One-dimensional Bose Gases — •Bing Yang[1,3], Yang-Yang Chen[2], Yong-Guang Zheng[1,3], Hui Sun[1,3], Han-Ning Dai[1,3], Xi-Wen Guan[2,4], Zhen-Sheng Yuan[1,3], and Jian-Wei Pan[1,3] — [1]Hefei National Laboratory for Physical Science at Microscal and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [2]State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan Institute of Physics and Mathematics, Chinese Academy of Science, Wuhan 430071, Wuhan — [3]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [4]Department of Theoretical Physics, Research School of Physics and Engineering, Australian National University, Canberra ACT 0200, Australia

We report an observation of quantum criticality and the TLL in a system of ultracold 87Rb atoms within 1D tubes. The universal scaling laws are measured precisely and the characteristic critical temperatures are determined by the double-peak structure of specific heat, confirming the existence of three phases: classical gas, quantum critical region and the TLL. The Luttinger parameter estimated from the observed sound velocity approaches the measured Wilson ratio (WR), which reveals the collective nature of the TLL and the quantum fluctuations.

Q 31.3 Tue 17:00 P OGs

Universal many-body scattering matrix for strong sound-wave turbulence in a dilute Bose gas — •Isara Chantesana[1,2,3] and Thomas Gasenzer[1,3] — [1]Kirchhoff-Institut für Physik, Ruprect-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Ruprect-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Far-from equilibrium dynamics of a dilute Bose gas is studied by means of the two-particle irreducible effective action formalism. We investigate the properties of non-thermal fixed points predicted previously, which are related to non-perturbative strong wave turbulence solutions of the many-body dynamic equations. The key ingredient of our approach is a universal many-body scattering matrix in the infrared limit, independent of the details of the microscopic interactions, which is derived by a resummation of 2PI diagrams. The Boltzmann scattering integral is analyzed in order to find the scaling at the fixed points which correspond to scaling exponents of sound wave turbulence. The dynamics obtained depends on approximate conservation laws in momentum space, the scaling behaviour of the scattering matrix and the dimensionality.

Q 31.4 Tue 17:00 P OGs

Atom-cavity physics with a Bose-Einstein condensate in an ultra-narrow band resonator — •Jens Klinder[1], Christoph Georges[1], Jose Vargas[1], Hans Kessler[1], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Wilczek Quantum Center, Zhejiang University of Technology

Bose-condensed atoms are trapped in a cavity operating in the ultimate quantum regime, when the Purcell factor exceeds unity and the frequency shift associated with scattering of a single photon exceeds the cavity bandwidth. We explore topics such as recoil resolved cavity sideband cooling [5], non-linear Bloch oscillations [4], matter wave superradiance [3], physics of the Dicke model [2] and the bosonic Hubbard model with infinite range retarded interactions [1].

[1] J. Klinder et al., PRL 115, 230403 (2015).
[2] J. Klinder et al., PNAS 112, 3290 (2015).
[3] H. Keßler et al., PRL 113, 070404 (2014).
[4] H. Keßler et al., NJP 18, 102001 (2016).
[5] M. Wolke et al., Science 337, 85-87 (2012).

Q 31.5 Tue 17:00 P OGs

Beyond mean-field dynamics of ultra-cold bosonic atoms in elongated traps — •Valentin Bolsinger[1,2], Sven Krönke[1,2], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We explore numerically the impact of dimensionality on the quantum dynamics of interacting bosons tunneling in a three dimensional double well including particle correlations. Such kind of numerical simulations are very challenging, due to (i) different participating length scales in modeling the short-range interactions in three dimensional traps and (ii) the exponential scaling of complexity with the number of atoms. Also a sketch of our numerical method is given, which is based on the recently developed ab-initio Multi-Layer Multi-Configurational Time- Dependent Hartee method for Bosons (ML-MCTDHB) [J. Chem. Phys. 139, 134103 (2013)], and which uses the fact that in elongated traps strong spatial correlations are suppressed due to the energy scales in the longitudinal and transversal direction. Our implementation has got a linear scaling in the number of grid points in contrast to other methods, using a product grid, with cubic scaling [arXiv:1608.04710].

Q 31.6 Tue 17:00 P OGs

Loading and in-situ fluorescence imaging of ultracold potassium in an optical trap — •Tobias Wintermantel, Henrik Hirzler, Alda Arias, Stephan Helmrich, Graham Lochead, and Shannon Whitlock — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Ultracold atoms provide a versatile toolbox to study many-body physics with full access to the underlying microscopic properties. We are currently setting up an experiment for potassium atoms confined to reduced dimensions to study the effect of long-range interactions introduced by Rydberg excitation.

We report on a major upgrade of the experimental apparatus to include gray molasses cooling and a quantum gas microscopy setup. Applying gray molasses cooling in a tight optical trap enhances the direct loading from a compressed magneto-optical trap. Low temperatures and high phase-space densities are reached combined with fast experimental cycle times of $\lesssim 1$ s. To image the atoms we placed an aspheric objective lens inside the vacuum chamber, which allows direct access to the spatial correlations between atoms. We present the first fluorescence images of potassium-39 atoms in the dipole trap using gray molasses.

Q 31.7 Tue 17:00 P OGs

Non-equilibrium dynamics of an F=1 spinor Bose-Einstein condensate — •Kevin Geier[1], Christian-Marcel Schmied[1], Sebastian Erne[2,3], 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]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Wien, Austria

We study the dynamics of an F=1 spinor Bose-Einstein condensate in one spatial dimension out of equilibrium by means of semi-classical simulations. Our main focus lies on sudden quenches within the paramagnetic phase, where the system is quenched near the critical point of a phase transition by varying an external magnetic field. The time evolution of the resulting non-equilibrium state including quantum effects is studied within the framework of the truncated Wigner approximation. To this end, the coupled Gross-Pitaevskii equations for the fundamental fields are solved numerically using higher-order time-splitting Fourier pseudospectral methods. We observe the formation of soliton-like excitations and study their link to the build-up of correlations in the system. By continuously tuning the interaction away from an integrable point of the system, we further investigate the effects of non-integrability on the observed dynamics. Our results are put into relation with the concept of non-thermal fixed points and critical phenomena.

Q 31.8 Tue 17:00 P OGs

Dynamics of a one-dimensional two-component Bose gas quenched to criticality. — •Martin Rabel, Markus Karl, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

We study the dynamics of a two-component Bose gas after a parameter quench into the proximity of a quantum critical point using analytical, real-time effective-action techniques. The relative degrees of freedom within the system can be described by a quasi-spin 1/2 model. This model is subject to a mean-field paramagnetic to ferromagnetic quantum phase transition. For the full model this corresponds to a transition from a miscible to an immiscible phase. The transition is investigated in a dynamical setup: The initial state is the ground-state configuration far away from criticality. Following a sudden quench to criticality the time evolution of the emerging spin fluctuations is analysed. In the one-dimensional system under investigation, the non-vanishing energy introduced by the quench leads to a finite correlation length during the induced time evolution. The finite critical correlation length is determined within a leading-order $1/N$ approximation. The obtained analytical results are compared with Truncated-Wigner numerical simulations.

Q 31.9 Tue 17:00 P OGs

Goldstone mode in the quench dynamics of an ultracold BCS Fermi gas: A full Bogoliubov-de Gennes approach — •Peter Kettmann[1], Simon Hannibal[1], Mihail Croitoru[2], Vollrath Martin Axt[3], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster — [2]Condensed Matter Theory, University of Antwerp — [3]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 an 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 (BdG) formalism. Extending previous studies, we use a full BdG approach instead of the truncated Anderson solution. This improves the validity in the strong-coupling regime and ensures a correct coupling of the Goldstone mode to the trapping potential.

We study the impact of this extension on the dynamics of the single-particle excitations and find an overall good qualitative agreement of both solutions. However, some significant deviations occur predominantly in the case of strong coupling.

Q 31.10 Tue 17:00 P OGs

Universal scaling and non-thermal fixed points in spin systems — •Stefanie Czischek[1], Halil Cakir[1], Markus Karl[1], Michael Kastner[2], Markus K. Oberthaler[1], and Thomas Gasenzer[1] — [1]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institute of Theoretical Physics, University of Stellenbosch, Stellenbosch 7600, South Africa

We study the dynamical build-up of correlations after sudden quenches in spin systems using the discrete truncated Wigner approximation. In particular, we consider quenches from large external fields into the vicinity of a quantum critical point within the paramagnetic phase. We calculate correlation lengths and study their time evolution at different distances from the critical point. For the transverse-field Ising chain, we find that the discrete truncated Wigner approximation is in good agreement with exact analytical and numerical results. Our exact results show that the correlation function takes the form given by a generalized Gibbs ensemble already after short times and small relative distances, which is also found in the discrete truncated Wigner approximation. The agreement of both results for quenches into the vicinity of the critical point suggests that the discrete truncated Wigner approximation may be used to determine the correlation dynamics after quenches for spin systems which are not exactly solvable, in one and higher dimensions.

Q 31.11 Tue 17:00 P OGs

Probing Relaxation at the Many-Body Localization Transition with Ultracold Fermions in Optical Lattices — •Sebastian Scherg[1,2], Henrik Lüschen[1,2], Pranjal Bordia[1,2], Ulrich Schneider[1,2,3], 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]Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom

The phenomenon of Many-Body Localization (MBL) describes a generic non-thermalizing phase in which quantum information can persist locally up to infinite times. This phase is separated from a phase obeying the Eigenstate Thermalization Hypothesis via a disorder driven, dynamical phase transition, which happens not only in the ground state but over an extended range of excited states. While the dynamical structure deep in the MBL phase is arguably well understood in one dimension, there is a paucity of results close to the critical point and in higher dimensions.

In this work, we report on the observation of MBL in one and two dimensions. We directly probe the transition points finding critically slow relaxation below the critical disorder strength in both 1D and 2D. The slow dynamics in 1D can be attributed to Griffiths type effects. We highlight the importance of interactions, which strongly govern the behavior around the critical point.

Q 31.12 Tue 17:00 P OGs

Sub-Doppler laser cooling of fermionic 40K atoms in gray optical molasses — •Max Hachmann, Robert Büchner, Raphael Eichberger, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg

Most experiments on quantum degenerate gases begin with a laser cooling phase that is followed by evaporative cooling in a conservative trap. The final quantum degeneracy strongly depends on the temperature at the end of the laser cooling phase and sub-Doppler cooling is often a key ingredient for initiating efficient evaporation. In our experiment for fermionic 40K a cooling cycle on the D2 transition for a bright optical molasses has been used. However, 40 K features a narrow hyperfine structure in the excited state of the D2 transition that hinders efficient sub-Doppler cooling by cooling to the red of this transition. The same is true for other isotopes of potassium and lithium. To overcome this limitation a gray molasses cooling scheme on the D1 transition at 770 nm can be implemented to produce cold and dense atomic samples. Here we report on the current progress of the experimental implementation.

Q 31.13 Tue 17:00 P OGs

Fermi Surface Deformation in Dipolar Fermi Gases — •Vladimir Veljić[1], 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 a recent time-of-flight (TOF) expansion experiment with ultracold polarized fermionic erbium atoms, TOF images show that the atomic cloud has an ellipsoidal shape, with an elongation in the direction of atomic dipoles [1]. The Hartree-Fock mean-field theory presented in Refs. [2,3], which was restricted to the orientation of dipoles along one of the harmonic trap axes, is generalized here for an arbitrary orientation of dipoles. Afterwards, using this approach we analyze the resulting Fermi surface deformation, calculate TOF dynamics, and solve the corresponding Boltzmann-Vlasov equation within the relaxation-time approximation in the vicinity of a new equilibrium configuration by using a suitable rescaling of the equilibrium distribution. The resulting ordinary differential equations of motion for the scaling parameters are solved numerically for experimentally relevant parameters at zero temperature. A comparison of our analytical and numerical results with the Innsbruck experimental results [1] is also presented.

[1] K. Aikawa, et al., Science **345**, 1484 (2014).
[2] F. Wächtler, A.R.P. Lima, and A. Pelster, `arXiv:1311.5100` (2013).
[3] V. Veljić, A. Balaž, and A. Pelster, `arXiv:1608.06448` (2016).

Q 31.14 Tue 17:00 P OGs

Towards second sound in a quasi two dimensional Fermi gas — •Daniel Hoffmann, Thomas Paintner, Wolfgang Limmer, and Johannes Hecker Denschlag — Universität Ulm, Institut für Quantenmaterie, Deutschland

Excitations in ultracold quantum gases have become a versatile tool to unveil fundamental thermodynamics. Especially the properties of superfluidity have been investigated extensively using local or global excitations. One phenomena which has recently been demonstrated in a quantum gas experiment is second sound excitation (see [1]). In this experiment entropy waves were excited in a suprafluid/normal fluid mixture and were detected by means of density modulation.

In the project presented here, we extend the work on second sound to quasi two dimensional gases. We use a degenerate Fermi gas of ^{6}Li loaded into a highly anisotropic trap, where the conditions of a quasi 2D Fermi gas can be fulfilled. To excite second sound, we use an intensity-modulated laser beam focused on the trap center to generate entropy waves. Detecting density modulations in the Fermi gas enables us to extract the second sound excitation. Our presentation shows first results towards second sound in a quasi 2D interacting Fermi gas.

[1]: Sidorenkov et al., Nature 498, 78-81 (2013)

Q 31.15 Tue 17:00 P OGs

Quench dynamics and equilibrium behavior in a spinless Fermi-Hubbard ladder with dipolar interactions — •Philipp Fabritius and Shannon Whitlock — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

We report on theoretical simulations of a spinless Fermi-Hubbard model on a two-leg ladder with anisotropic long-range dipolar interactions. Using a density-matrix renormalization group approach we obtain the quantum phase diagram. We also present results on the dynamical evolution of the system following a quantum quench from an insulating to an interlayer superfluid phase. These results have relevance for future experiments which aim to use quantum gas microscopy to reveal exotic superfluid and magnetic phases with ultracold atoms.

Q 31.16 Tue 17:00 P OGs

An experiment to initialize and study the Fermi-Hubbard model atom by atom — •Phillip Wieburg, Kai Morgener, Thomas Lompe, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

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 build up a Fermi-Hubbard system site by site using optical microtraps. Each microtrap will contain a single atom cooled to the vibrational ground state by Raman-sideband cooling. This technique combines fast experimental cycle times with single site addressability and detection and allows studying the fundamental processes governing the Fermi-Hubbard model in a bottom-up approach.

Here we report upon the commissioning of this new experiment, which is going to be able to cool a gas of 40K to quantum degeneracy as well as to directly lasercool single atoms into optical microtraps. We have already lasercooled 39K and 40K atoms and trapped them magnetically. Further cooling of the atoms will be performed using Raman-sideband cooling [1,2]. In order to image and to manipulate the atoms with high spatial resolution, our setup is equipped with a novel type achromatic imaging system located inside the vacuum chamber.

[1] A.M. Kaufman et al., Physical Review X 2 041014 (2012).
[2] L. W. Cheuk et al., Phys. Rev. Lett. 114, 193001 (2015).

Q 31.17 Tue 17:00 P OGs

Anomalous heating in ion traps: where does the noise originate? — •Carsten Henkel[1], Henning Kaufmann[2], and Ulrich Poschinger[2] — [1]Universität Potsdam — [2]Johannes-Gutenberg-Universität Mainz

Trapped ions that are laser-cooled to the ground state of a Paul trap provide a promising platform for quantum information processing and surface analysis. The ions are subject to fluctuating electric fields emanating from the surrounding electrodes which lead to a finite heating rate whose detailed behaviour is not yet fully understood (patch potentials, surface adsorbates, temperature and distance dependence ...)[1]. Building on a recent model with metallic electrodes covered by a thin lossy dielectric [2], we investigate the spatial distribution of the charge fluctuations that generate the electric field noise. We analyze for example the interference that is at the origin of the maximum of noise for films with a certain thickness [3, 4]. The aim is to mitigate anomalous heating with suitably coated electrodes that screen the dominant noise sources.

[1] M. Brownnutt, M. Kumph, P. Rabl, and R. Blatt, Rev. Mod. Phys. 87 (2015) 1419
[2] M. Kumph, C. Henkel, P. Rabl, M. Brownnutt, and R. Blatt, New J. Phys. 18 (2016) 023020
[3] S. Bauer, Am. J. Phys. 60 (1992) 257
[4] S. A. Biehs, D. Reddig, and M. Holthaus, Eur. Phys. J. B 55 (2007) 237; S. A. Biehs, Eur. Phys. J. B 58 (2007) 423

Q 31.18 Tue 17:00 P OGs

A hybrid atom-ion trap for ultracold Li and Yb$^+$ — •Jannis Joger[1], Henning Fürst[1], Norman Ewald[1], Thomas Secker[2], Thomas Feldker[1], and Rene Gerritsma[1] — [1]Institute of Physics, University of Amsterdam, Netherlands — [2]Institute for Coherence and Quantum Technology, TU Eindhoven, Netherlands

Our setup for realising a hybrid system of ultra-cold atoms and ions is presented. This setup allows studying the quantum dynamics of mixtures of fermionic atoms and ions. Recent experiments have shown that the time-dependent trapping field of the ions can cause heating in hybrid atom-ion systems [1]. One way to mitigate this problem is to employ ion-atom combinations with a large mass ratio [2]. The highest convenient mass ratio - for species that still allow for straightforward laser cooling - is achieved by using the combination ^{171}Yb$^+$ and ^{6}Li.

Combining ion trapping technology with ultra-cold lithium poses particular challenges that we address on this poster. We present numerical simulations showing that the s-wave limit may be reached in our setup, opening up the possibility of studying atom-ion Feshbach resonances [3] and show our first experimental results of atom-ion interactions.

[1] Z. Meir et al., arXiv:1603.01810 (2016)
[2] M. Cetina et al., Phys. Rev. Lett. 109, 253201 (2012).
[3] M. Tomza, C.P. Koch and R. Moszynski, Phys. Rev. A 91, 042706 (2015).

Q 31.19 Tue 17:00 P OGs

Laser cooling of Dysprosium — •Niels Petersen, Florian Mühlbauer, Carina Baumgärtner, Lena Maske, and Patrick Windpassinger — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 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 discuss the relevant properties of dysprosium and present our laser system and vacuum design. We present spectroscopic measurements of the relevant cooling transitions and show our progress towards laser cooling of dysprosium atoms in a magneto optical trap.

Q 31.20 Tue 17:00 P OGs

The role of particle (in-)distinguishability for many-particle dynamics in optical lattices — •Tobias Brünner, Gabriel Dufour, Alberto Rodriguez, and Andreas Buchleitner — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany

Much attention has been dedicated so far to the dynamical impact of interactions - which often can be associated with the progressive suppression of coherence phenomena. On the other hand, little is known on the fundamental role of the interacting particles* degree of mutual (in-)distinguishability in such experiments, while we have learnt from a new generation of photonic interference experiments and theory that controlling the degree of (in-)distinguishability unveils a panoply of novel many-particle interference phenomena. We import this program into the realm of controlled, interacting many-particle quantum systems, specifically for cold atoms in optical lattices, and identify statistical, experimentally readily accessible quantifiers to infer the particles* degree of distinguishability.

Q 31.21 Tue 17:00 P OGs

Quantum Hall physics with quantum walks in a synthetic magnetic field — •Muhammad Sajid, Dieter Meschede, and Andrea Alberti — Wegelerstr. 8 - 53115

Simulation of quantum transport with discrete-time quantum walks (DTQWs) have been realized in various experiments including ultracold neutral atoms in optical lattices [1]. For example, the behavior of charged particles in a periodic potential subject to an external electric field has been simulated with neutral atoms in spin-dependent one-dimensional optical lattices [2].

Here, we propose a scheme based on DTQWs to recreate integer quantum Hall (IQH) physics with pseudo-spin-1/2 particles. Quantum walks are particularly suited to study the limit of strong fields. We compute the bulk topological invariants, i.e. the Chern numbers of the bands, of DTQWs in a synthetic magnetic field. Further, we discuss an experimental proposal based on realistic experimental conditions, which uses neutral atoms to implement synthetic magnetic fields in a DTQW. Our experimental proposal permits to dial any synthetic magnetic field landscape, including those with sharp spatial boundaries, along which matter waves are expected to flow without dissipation into the bulk.

[1] M. Karski et al., Science 325, 174 (2009). [2] M. Genske et al., Phys. Rev. Lett. 110, 190601 (2013).

Q 31.22 Tue 17:00 P OGs

Imaging topologically protected transport in 2D optical lattices — •Falk-Richard Winkelmann, Stefan Brakhane, Alexander Knieps, Geol Moon, Gautam Ramola, Carsten Robens, Max Werninghaus, Wolfgang Alt, Dieter Meschede, and Andrea Alberti — Institut für Angewandte Physik - Uni Bonn

Discrete time quantum walks (DTQWs) of neutral atoms in 2D optical lattices provide a versatile platform to simulate topological phenomena arising in condensed matter and artificial gauge fields.

With our recently completed 2D quantum simulator we investigate topologically protected transport, using DTQWs in two dimensions [1].

We make use of polarization-synthesized lattice beams todeterministically transport neutral Cs atoms depending on their internal state. A high numerical aperture (NA = 0.92) objective lens enables us to image and address atoms with single site resolution [2].

We present how we plan to utilize aspatial light modulator to realize a spatially resolved coin operation, which will enable us to prepare topologically protected edge states between regions with different topological phases.

[1] Groh, et al. Robustness of topologically protected edge states in quantum walk experiments with neutral atoms. Phys. Rev. A, 94, Jul 2016. [2] Robens, et al. A high numerical aperture (na = 0.92) objective lens for imaging and addressing of cold atoms. arXiv:1611.02159, 2016.

Q 31.23 Tue 17:00 P OGs

Rydberg excitations of cold atoms inside a hollow-core fiber — •Maria Langbecker, Mohammad Noaman, Chantal Voss, Maik Selch, Florian Stuhlmann, and Patrick Windpassinger — QUANTUM, 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. Using this scheme, novel photonic states can be generated and studied with possible applications in quantum information and simulation.

This poster presents our experimental setup with laser cooled Rubidium atoms inside a hollow-core fiber. We explain the details of our transport procedure of the cold atoms into the fiber using an optical conveyor belt and show the first measurements of cold Rydberg excitations inside the fiber. In addition, we present the characterization of Kagomé-type hollow-core fibers whose properties allow for simultaneous atom guiding and two-photon Rydberg EIT excitation. Finally, we show our progress towards Rydberg quantum optics in a quasi-one-dimensional geometry.

Q 31.24 Tue 17:00 P OGs

Toward a photon-photon quantum logic gate based on Rydberg interactions — •Steffen Schmidt-Eberle, Daniel Tiarks, Thomas Stolz, Stephan Dürr, and Gerhard Rempe — MPI für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

The experimental realization of a photon-photon quantum logic gate based on a scheme which is not inherently probabilistic was a longstanding goal, which has been reached only recently, using a single atom in an optical resonator [1]. We pursue the same goal following a different approach in which the required strong interactions are generated by the gigantic van der Waals interaction between Rydberg atoms. A crucial ingredient needed for such a gate is an optical π phase shift generated by a single photon, which we demonstrated recently [2]. We now extended the scheme of Ref. [2] by storing an incoming photonic polarization qubit in a quantum memory consisting of an atomic ground state and a Rydberg state. We report on the implementation of this scheme in our experimental setup and quantitative studies of its performance.

[1] B. Hacker et al. Nature 536, 193 (2016).
[2] D. Tiarks et al. Science Advances 2, e1600036 (2016).

Q 31.25 Tue 17:00 P OGs

Probing many-body states of interacting Rydberg atoms via fluorescence imaging. — •Henrik Hirzler, Tobias Wintermantel, Stephan Helmrich, Alda Arias, Graham Lochead, and Shannon Whitlock — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Trapped ultracold atoms excited to Rydberg states provide a widely controllable platform for strongly-interacting many-body physics. We recently showed that the competition between driving fields, dissipation and interactions leads to several interesting dynamical regimes which exhibit scaling behavior [1]. We expect this is associated with the emergence of strong spatial correlations between the excited atoms. To probe these correlations we will optically down-pump the excited Rydberg atoms and then measure their fluorescence using a high-resolution imaging system, consisting of a high-NA objective lens and a high quantum efficiency camera. We will report progress towards spatially resolving correlations induced by Rydberg-Rydberg interactions down to single atom level.

[1] Helmrich, S et al. "Scaling of a long-range interacting quantum spin system driven out of equilibrium", arXiv:1605.08609, 2016

Q 31.26 Tue 17:00 P OGs

Simulation of 3D atomic Bragg beam splitters — •Antje Neumann and Reinhold Walser — Institut für Angewandte Physik TU-Darmstadt, Darmstadt, Germany

Atoms are the ultimate quantum sensors. In the configuration of an atom interferometer they provide the opportunity of high-precision rotation and acceleration sensing. Potential applications are inertial navigation, geological exploration and fundamental physics. In the QUANTUS free-fall experiments atom interferometry is the central method as well.

Like in optical systems, matter wave devices like traps, beam splitters and mirrors require specifications and ubiquitous imperfections need to be quantified. In particular, we study the response and aberrations due to spatio-temporal laser beam envelopes, wave front curvatures and spontaneous emission of a Bragg beam splitter. We present results of numerical and analytical studies of the velocity dependence of the complex reflectivities of the beam splitter. Finally, this is applied to obtain the diffraction efficiency of a Bragg beam splitter for thermal and Bose-condensed atomic ensembles.

Q 31.27 Tue 17:00 P OGs

Atomic lensing with aberrations — •Wolfgang Zeller[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS TEAM[1,2,3,4,5,6,7,8] — [1]Institut für Quantenphysik, Universität Ulm — [2]Institut für Quantenoptik, LU Hannover — [3]ZARM, Universität Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Physik, JGU Mainz — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham, UK — [8]Lab. Kastler Brossel, E. N. S., France

The field of light-pulse atom interferometers has made an enormous progress in precision with a wealth of applications since the first experiments 25 years ago. Improving the resolution by means of longer interferometer times is, however, accompanied by a loss in the signal-to-noise ratio because of the decreasing density of the cloud. Although atomic lensing (also known as delta-kick cooling) can mitigate this problem (see Ref. [1], for instance), we illustrate that possible "lens aberrations" caused by potential anharmonicities can give rise to non-trivial features of the atomic cloud [2]. In particular, we investigate their relevance in the context of recent QUANTUS and future high-precision experiments.

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.

[1] H. Müntinga et al., *Physical Review Letters* **11**, 093602 (2013).
[2] W. Zeller, A. Roura and W. P. Schleich, *in preparation.*

Q 31.28 Tue 17:00 P OGs

Geometric Phases in Light-Pulse Atom Interferometry — •Stephan Kleinert, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität 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 topological effects of the internal as well as the external degrees of freedom in atom interferometers. Within the general framework of the representation-free description of light-pulse atom interferometry [1] we separate the geometric phase from the dynamical phase contributions and propose an interferometer pulse sequence that measures the geometric phase.

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 31.29 Tue 17:00 P OGs

Elements of a guided electron based quantum electron microscope — •Robert Zimmermann, Philipp Weber, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen

This poster reports on the manipulation of free electrons using microwave electric fields applied to micro-structured chips. The working principle is the same as for the Paul trap, i.e. a microwave potential applied to electrodes causes an oscillating electric field by which the electrons can be guided [1]. Based on the first designs of a planar quadrupole guide [2][3] and of an electron beam splitter [4], we discuss the improved confinement from using two electrode chips. Lastly, the design of an electron resonator and its first experimental results are presented. In contrast to conventional electron optics, the transverse confinement naturally provides discretized motional quantum states that govern the electron motion. The goal is to employ these quantum states 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, R. Fröhlich, M. A. Kasevich and P. Hommelhoff; 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 31.30 Tue 17:00 P OGs

The moiré fieldmeter: an atom optics tool for electric and magnetic field measurements — •Andrea Demetrio[1], Pierre Lansonneur[2], Simon Müller[1], Patrick Nedelec[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg (DE) — [2]Institut de Physique Nucleaire de Lyon, Bâtiment Paul Dirac, 4 rue E. Fermi, 69622 Villeurbanne (FR)

We report on the development of a fieldmeter which employs the moiré effect to determine the magnitude of electric and magnetic fields in the experimental region.

The device is composed by three material gratings with micrometric periodicity. A diffused beam of particles going through the gratings forms a pattern with the same periodicity as the gratings themselves. A force acting on the particles causes a shift of this pattern, which is proportional to the acceleration perpendicular to the orientation of the slits. Comparing this shift for different ions, the intensity of the external fields can be measured. With the use of three ion species with different charge-to-mass ratios, it is possible to decouple the effects of magnetic and electric fields.

Here we show the use of this device in the scope of the ATLIX project (Antiproton Talbot-Lau Interferometry eXperiment) as a way to ensure that the fields inside the experimental region are below the critical limits which would hinder its realization. The data have been taken with the use of a ECR ion source in Heidelberg, where a prototype of the experiment is currently being built.

Q 31.31 Tue 17:00 P OGs

Nuclear spin register in diamond and their application — •Thomas Unden[1], Zhenyu Wang[2], Jorge Casanova[2], Boris Naydenov[1], Alex Retzker[3], Martin B. Plenio[2], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm — [2]Institut für Theoretische Physik, Universität Ulm — [3]Racah Institute of Physics, Hebrew University of Jerusalem

Nuclear spin register in diamond open several ways towards the understanding of future quantum technology. Using a single, cotrollable electron spin nearby, our nuclear register is controllable and can be used for quantum information tasks like quantum error correction as well as improved metrology.

Q 31.32 Tue 17:00 P OGs

Atom-chip interferometry with Bose-Einstein condensates — •Matthias Gersemann[1], Sven Abend[1], Martina Gebbe[2], Holger Ahlers[1], Hauke Müntinga[2], Christian Schubert[1], Wolfgang Ertmer[1], Claus Lämmerzahl[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

The small spatial and momentum width of ultracold atoms such as Bose-Einstein condensates (BEC) makes them very well suited for high precision atom interferometry. In our atom-chip setup we generate a ^{87}Rb BEC and are able to perform Bragg interferometry with high fidelity. Introducing a relaunch mechanism allows us to span a fountain geometry including all required atom-optical operations in a volume of less than a one centimeter cube. This geometry enables the operation of a quantum gravimeter based on a Mach-Zehnder type interferometer sequence with a free-fall time of $T = 25\,\mathrm{ms}$. Additionally techniques like delta-kick collimation, Stern-Gerlach type deflection, higher-order and double Bragg beam splitters are studied in detail. 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 numbers DLR 50WM1552-1557 (QUANTUS-IV-Fallturm).

Q 31.33 Tue 17:00 P OGs

Atom-chip based BEC sources for compact and transportable experiments — •H. Heine[1], J. Matthias[1], N. Grove[1], M. Sahelgozin[1], A. Kassner[2], M. Rechel[2], S. Abend[1], S. T. Seidel[1], W. Herr[1], M. C. Wurz[2], J. Müller[3], W. Ertmer[1], and E. M. Rasel[1] — [1]IQ, Leibniz Universität Hannover — [2]IMPT, Leibniz Universität Hannover — [3]IfE, Leibniz Universität Hannover

Cold atom interferometers are starting to be used as inertial sensors in geodetic measurement campaigns competing with state-of-the-art classical sensors but are limited in accuracy by the residual thermal expansion of the atomic ensemble. Meanwhile, atom chips have been used to create Bose-Einstein condensates (BECs) with high repetition rates, providing a source of low expanding atomic ensembles ideal for compact and transportable precision experiments.

On this poster we will contrast our current atom-chip source with the features of the next generation atom chips targeting higher flux, compactification and simplification. The flux can be increased by utilizing non-adhesive conjunction techniques, leading to better vacuum quality and hence lowering background collision losses. With advanced electrical contacting of the chip and simplification in the optical setup, very compact and transportable systems can be realized.

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.

Q 31.34 Tue 17:00 P OGs

Precision gravity measurements with Very Long Baseline Atom Inteferometry — •Christian Meiners, Dorothee Tell, Etienne Wodey, Dennis Schlippert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Gottfried Wilhelm Leibniz Universität Hannover

Matter-wave interferometers are a novel method for probing inertial forces as rotations and accelerations. By using quantum objects as test masses they can reach extremely high stability and low systematic uncertainty. One direction of development of these sensors is the compactification to make them applicable in field geodesy whereas an other development is to extend the baseline from tens of centimeters to several meters, to increase the sensitivity which scales with the free fall time squared. Our very long baseline atom interferometer (VLBAI) will not only establish a complementary method to state of the art gradiometers and superconducting gravimeters when operated with a single species but also aims at quantum tests of the universality of free fall at levels comparable to the best classical tests and beyond by utilizing two different atomic species.

We present our strategies and recent progress on the construction of a VLBAI facility in Hannover, implementing ultra-cold samples of rubidium and ytterbium atoms, a magnetically shielded interferomtry region, and a state of the art vibration isolation.

The VLBAI facility is a major research equipment funded by the DFG. We also acknowledge support from the CRCs 1128 "geo-Q" and 1227 "DQ-mat" and the RTG 1729.

Q 31.35 Tue 17:00 P OGs

A compact diode laser system for atom interferometry on a sounding rocket — •Vladimir Schkolnik[1,2], Ortwin Hellmig[3], André Wenzlawski[4], Jens Grosse[5], Anja Kohfeldt[2], Klaus Döringshoff[1], Andreas Wicht[2], Patrick Windpassinger[4], Klaus Sengstock[3], Claus Braxmaier[5,6], Markus Krutzik[1], Achim Peters[1,2], and The MAIUS Team[1,2,3,4,5,6,7] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]FBH Berlin — [3]U Hamburg — [4]JGU Mainz — [5]ZARM U Bremen — [6]DLR Bremen — [7]LU Hannover

Laser systems with precise and accurate frequencies are one of the key elements in modern precision experiments based on atom interferometers and atomic clocks. Future space missions including quantum interferometry based gravity mapping, tests of the equivalence principle or the detection of gravitational waves rely on robust and compact lasers with high mechanical and frequency stability.

Here we present a compact diode laser system for atom interferometry with ultra-cold atoms aboard sounding rockets. Our laser system is flight-proven through successful operation in the MAIUS mission. Design, assembly and qualification of the laser system as well as its performance during the flight are discussed.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant numbers DLR 50WM 1237-1240, and 1345.

Q 31.36 Tue 17:00 P OGs

Testing the Universality of Free Fall with cold atoms — •Henning Albers, Dipankar Nath, Logan L. Richardson, Dennis Schlippert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

The development of cold atom sensors has given rise to a unique and broad field of applications. They can be used for inertial sensing and as well as fundamental tests of the laws of physics. By performing a differential measurement of the Earth's local gravitational acceleration, g, of two distinct atomic species, namely ^{39}K and ^{87}Rb, we are able to provide a sensitive test of the Universality of Free Fall (UFF) with atomic test masses [1].

In this work, we show the recent progress towards testing the UFF with an inaccuracy on the level of 10^{-9}. To reach this goal we utilize an optical dipole trap at 1960 nm. In addition, the correction of ground coupled inertial noise, measured by a commercial seismometer, in an atom interferometer is an important aspect, both for the realization of transportable atom gravimeters, as well as the 10 m Very Long Baseline Atom Interferometer (VLBAI) apparatus working with Rb and Yb [2].

[1] D. Schlippert et al., Phys. Rev. Lett. 112, 203002 (2014)
[2] J. Hartwig et al., New J. Phys. 17, 035011 (2015)

Q 31.37 Tue 17:00 P OGs

Pushing quantum sensor technology towards ultra-compact and integrated setups — •Marc Christ[1], Achim Peters[1], Markus Krutzik[1], and The KACTUS Team[1,2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]Leibniz Universität Hannover

Reliable long-term operation of integrated quantum sensors in space imposes challenging requirements on the utilized technology and materials. In the last decade, the progress in miniaturization achieved in the context of the QUANTUS and LASUS collaborations greatly benefited from atom chip technology, microintegrated diode laser systems and compact opto-mechanics.

Within the KACTUS project, we explore innovative technologies to realize even more compact and integrated quantum sensor prototypes, for instance by implementing Magneto-optical traps and dipole laser setups on-chip. To achieve long lifetimes of Bose-Einstein condensates generated in these devices, the UHV performance is crucial.

We present the design of a versatile tool allowing mass spectrometry and gas rate measurements at 10^{-11} mbar base pressure. Combined with a sample transfer and conditioning system, UHV qualification of single components to medium sized assemblies is possible. This enables rapid prototyping of innovative, integrated setups and qualification of novel bonding techniques.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1648.

Q 31.38 Tue 17:00 P OGs

A cryogenic ion trap experiment for highly charged ions — •Steven A. King[1], Tobias Leopold[1], Peter Micke[1,2], Lisa Schmöger[1,2], Maria Schwarz[1,2], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [3]Institut für Quantenoptik, Universität Hannover, 30167 Hannover

Highly charged ions (HCI) with narrow optical transitions are promising systems for tests of fundamental physics and improved optical frequency standards. However, to fully make use of these systems the high charge state production needs to be combined with the techniques of single ion trapping at cryogenic temperatures.

We present a cryogenic ion trap setup for highest precision quantum logic spectroscopy of HCI. The HCI are extracted from a room temperature permanent magnetic EBIT and re-trapped in a Paul trap together with Be^+ ions [1]. These ions provide sympathetic cooling and act as the logic species in the quantum logic scheme. Initial data from our low vibration cryogenic system and Paul trap will be presented.

As the next step we will perform optical spectroscopy on the well investigated fine structure transition of Ar^{13+} and determine the isotope shift between $^{36}Ar^{13+}$ and $^{40}Ar^{13+}$.

[1] Schmöger et al., *Science* 347, 6227 (2015)

Q 31.39 Tue 17:00 P OGs

A fibre link for optical clock comparison between London and Paris — •Jochen Kronjäger[1], Giuseppe Marra[1], Olivier Lopez[2], Nicolas Quintin[2], Anne Amy-Klein[2], Won-Kyu Lee[3,4], Paul-Eric Pottie[3], and Harald Schnatz[5] — [1]NPL, Teddington, UK — [2]LPL, Universite Paris 13, Villetaneuse, France — [3]LNE-SYRTE, Observatoire de Paris, UPMC, Paris, France — [4]KRISS, Daejon 305-340, South Korea — [5]PTB, Braunschweig, Germany

Comparing independently built optical clocks is the main way of benchmarking this rapidly developing technology. Comparisons between different National Metrology Labs have traditionally employed satellite links which, however, lack the stability and accuracy needed for optical clocks. Optical frequency transfer through long-haul fibre links enables comparisons between remotely located optical clocks with a transfer stability and accuracy much better than state-of-the art clocks.

The London-Paris optical frequency fibre link has been established to compare the optical clocks developed at NPL and SYRTE. It utilizes around 800 km of commercial telecommunication fibre with 10 bidirectional optical amplifiers (EDFAs) installed at regular intervals. Our setup employs a novel hybrid topology which combines conventional active fibre noise compensation and two-way technology. We present details of the link implementation and characteristics, along with results from initial optical clock comparisons campaigns.

Together with the link between France and Germany, the London-Paris link will allow simultaneous comparisons of multiple remote clocks and chronometric levelling between the UK and Europe.

Q 31.40 Tue 17:00 P OGs

Evaluation of a sub-hertz cavity for an $^{27}Al^+$ optical frequency standard — •Lennart Pelzer[1], Stephan Hannig[1], Johannes Kramer[1], Nils Scharnhost[1], Steven King[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

We present a 39.5 cm long ULE cavity for the stabilisation of a 1070 nm laser. After two frequency doubling stages, the light will probe the $^1S_0 \leftrightarrow {}^3P_0$ clock transition of a trapped Al^+ ion, which has a natural linewidth of $2\pi\times$ 8 mHz. To achieve the necessary level of stability to resolve such a narrow transition, environmental perturbations to the cavity length have to be minimised. A long ULE spacer together with mirrors having a large radius of curvature suppresses the contribution of Brownian thermal noise, which poses the most fundamental limit to the achievable stability, to an estimated fractional level of 7×10^{-17}. Especially for such a long cavity spacer, vibration-induced deformations have to be cancelled by exploiting symmetries in the spacer. The evaluation of stability-limiting effects shows the progress in suppressing all relevant noise sources below the thermal noise limit.

Q 31.41 Tue 17:00 P OGs

Enhancing the sensitivity of single photon recoils in spectroscopy with non-classical states — •Marius Schulte[1], Niels Lörch[2], Piet. O. Schmidt[3,4], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover, Callinstrasse 38, 30167 Hannover, Germany — [2]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [3]QUEST Institut, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [4]Institute for Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany

The sensitivity in measuring displacements in phase space based on absorbed photons in spectroscopy is discussed. Non-classical squeezed states, cat states and small linear combinations of Fock states are shown to result in an enhancement of sensitivity, compared to the ground state of motion. A theoretical model gives the dynamics of photon recoil spectroscopy in terms of a Fokker-Planck equation thereby including incoherent processes allowing to compare the stability of spectroscopy states with respect to additional diffusion. This also predicts Doppler effects leading to systematic shifts in the observed resonance frequency. Limitations on the sensitivity based on imperfect state preparation and the attainable quantum Fisher information are discussed.

Q 31.42 Tue 17:00 P OGs

Aufbau eines hochstabilen Einzel-Ionen-Mikroskop — •Felix Stopp[1], Georg Jacob[1], Karin Groot-Bering[1], Mark Keil[2], Ron Folman[2] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Atom Chip Group, Dept. of Physics, Ben-Gurion University of the Negev, 84105 Be'er Sheva, Israel

Einzelne lasergekühlte Ionen, die deterministisch aus einer linearen Paulfalle extrahiert werden können, erlauben eine neuartige Methode der Mikroskopie mit einer räumlichen Auflösung von wenigen Nanometer [1]. Die aktuell experimentell erreichte Fokusgröße von 6 nm ist durch mechanische Vibrationen und thermische Drifts im Aufbau begrenzt. Wir diskutieren die Konstruktion eines Aufbaus, in dem ein kompaktes, hochstabiles Fallen- und Ionenlinsendesign zur Anwendung kommen wird. Dazu wird der Teilchenstrahl in kurzen Entfernungen über der zu analysierenden Oberfläche fokussiert und nach der Wechselwirkung in einem Detektor registriert. Weiterhin geplant ist, das Ion nach der Wechselwirkung erneut einzufangen und seinen Quantenzustand zu detektieren. Dies ermöglicht Energieverlustspektroskopie mit Ionen, die nah über zu untersuchende Oberflächen gelenkt werden. Das Ion dient so als Sonde von elektrischen und magnetischen Feldern, bzw. zur Untersuchung von nano- und mikro-strukturierten Proben.

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

Q 31.43 Tue 17:00 P OGs

Superresolving Imaging of arbitrary Arrays of Thermal Light sources in the Visible using Multiphoton Interferences — •Anton Classen[1,2], Felix Waldmann[1], Sebastian Giebel[1], Raimund Schneider[1,2], Daniel Bhatti[1,2], Thomas Mehringer[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen

Measuring higher-order photon correlations is an emerging technique in the field of imaging to overcome the classical resolution limit [1-4]. We propose to use higher-order spatial photon cross-correlations measured in the far field of statistically independent thermal light sources (TLS) to reconstruct arbitrary two-dimensional TLS source geometries. The technique generalizes an earlier imaging scheme which resolves one-dimensional source arrangements with sub-Abbe resolution [4]. By choosing specific detector positions the technique allows to sequentially isolate the spatial frequencies of the sample within different correlation orders, enabling us to retrieve the source distribution with increased accuracy. We present experimental data verifying the theoretical predictions and discuss the conditions under which sub-Abbe resolution is achieved. [1] Oppel et al., Phys. Rev. Lett. 109 233603 (2012); [2] T. Dertinger et al., Q. Rev. Biophys. 46, 210 (2013); [3] D. G. Monticone et al., Phys. Rev. Lett. 113, 143602 (2014); [4] A. Classen et al., accepted for publication in Phys. Rev. Lett.

Q 31.44 Tue 17:00 P OGs

Cryogenic ion trap apparatus for quantum information processing with ^{9}Be$^+$ ions — •Fabian Ude[1], Timko Dubielzig[1], Sebastian Grondowski[1], Henning Hahn[2,1], Giorgio Zarantonello[2,1], Martina Wahnschaffe[2,1], Armado Bautista-Salvador[2,1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch-technische-Bundesanstalt Braunschweig

We report on a cryogenic ion trap apparatus for quantum information processing and quantum simulation experiments with ^{9}Be$^+$ ions in surface-electrode ion traps. The ion trap is cooled by a vibration isolated closed cycle cryostat to reduce the detrimental effect of anomalous motional heating. We characterize the vibration isolation using a Michelson interferometer and find residual vibration amplitudes <20 nm 0-pk. We report on the setup of the cryogenic shields and thermal management for bringing in a large number of DC and RF control signals. We present the trap RF drive based on a miniaturized cryogenic helical resonator and discuss its performance.

Q 31.45 Tue 17:00 P OGs

Establishing gate fabrication for advanced multi-layer SiGe Quantumdots — •Philip Schrinner[1,3], Arne Hollmann[1], Tim Leonhardt[1], Stefan Trellenkamp[2], and Lars Schreiber[1] — [1]JARA Institute for Quantum Information, RWTH Aachen University, Germany — [2]Peter Grünberg Institute (PGI-8), FZ Jülich, Germany — [3]Center for Nanotechnology, Westfälische Wilhelms-Universität Münster, Germany

Electron spin qubits in electrostatically defined Si/SiGe quantum dots combine excellent coherence times (T2* = 1 mu s [1]), small feature size and CMOS compatibility and therefore promise to be an excellent candidate for a scalable semiconductor based universal quantum computer. In comparison to previous fabrication layouts an advanced multi-layer gate design has been shown to further decrease the number of gates per qubit, the size of the gate pattern, charge noise and gate cross-coupling [2,3]. My work focuses on the development of such fabrication technology by isolating three expected fabrication challenges and address them with the fabrication of corresponding test structures. I will present methods to fabricate an array of sub 30 nm wide gates with a sub 70 nm pitch, electrically isolated by a few nano-meter thick oxide layer and the alignment precession of gate layers with respect to each other. As a result, I will give all the required ingredients to fabricate multi-layer quantum dot gate patterns for multi-qubit devices. [1] E. Kawakami et al., Nature Nano-tech. 9, 666 (2014). [2] G. Borselli et al., Nanotechnology 26, 375202 (2015). [3] D. M. Zajac et al., Appl. Phys. Lett. 106, 223507 (2015).

Q 31.46 Tue 17:00 P OGs

Cooling and Reset of a Superconducting Qubit using Quantum Optimal Control — •Daniel Basilewitsch[1], Rebecca Schmidt[2], Sabrina Maniscalco[2], Dominique Sugny[3,4], and Christiane Koch[1] — [1]Theoretical Physics, University of Kassel, Kassel, Germany — [2]Turku Center for Quantum Physics, University of Turku, Turku, Finland — [3]Laboratoire Interdisciplinaire Carnot de Bourgogne, CNRS-Université de Bourgogne, Dijon, France — [4]Institute for Advanced Study, Technical University of Munich, Garching, Germany

The requirement of fast and accurate initialization of qubits into known initial states is one important key for the realization of quantum information processing tasks. Our approach is to achieve cooling of a superconducting qubit by means of controlled coupling to an auxiliary qubit, in order to use the auxiliary qubit as entropy sink. Using optimal control theory (OCT), we show that the maximal fidelity and minimal time for realizing this fidelity depend on the initial state of the bipartite system consisting of primary and auxiliary qubit. When starting from a factorized state, the maximal fidelity is determined by the initial purity of the auxiliary qubit, while the minimal time is limited my the coupling strength. In case of correlated initial states this limit can be exceeded when allowing for time-dependent controls on the primary qubit. This shows that correlations can be exploited for resetting the qubit.

Q 31.47 Tue 17:00 P OGs

Experimental analysis of decoherence mechanisms in a single-atom memory for photonic qubits — •Stefan Langenfeld, Matthias Körber, Olivier Morin, Andreas Neuzner, Stephan Ritter, 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. To improve on achievable coherence times, a thorough understanding of the relevant decoherence mechanisms is indispensable. Our system consists of a single atom trapped in a two-dimensional optical lattice in a high-finesse cavity [1]. The qubit is initially stored in a superposition of Zeeman states, making magnetic field fluctuations the dominant decoherence mechanism. We reduce the magnetic field induced decoherence by transferring the qubit into a decoherence-free subspace. Here, the coherence time is no longer limited by magnetic field noise, but by differential light shifts of the new qubit states. We will discuss how this new limitation can be overcome and which future steps can be taken to further increase the coherence time.

[1] H. Specht et al., Nature 473, 190 (2011).

Q 31.48 Tue 17:00 P OGs

Carving of atomic Bell states with a cavity — •Bastian Hacker, Stephan Welte, Severin Daiss, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Entangled pairs of atoms are ideal for the study of fundamental quantum correlations and as a resource for many tasks in quantum information processing. At the node of an optical quantum network they can be applied for local information processing tasks, and, when strongly coupled to flying qubits, as a resource for more complex network operations. Our experiment applies the technique of quantum state carving to create entangled states of two rubidium atoms trapped in one optical cavity. The cavity strongly couples both atoms to the field of a reflected light pulse and thereby allows us to perform projective measurements on the combined two-atom state that can lead to maximally entangled states in a heralded fashion. Using coherent qubit control and several protocols we demonstrate the creation of all four Bell states. Dependence on experimental parameters will be discussed. Our entangled atoms in a cavity are an ideal starting point for applications like entanglement distribution, distributed quantum computing or a quantum repeater.

Q 31.49 Tue 17:00 P OGs

Entangled Photon Pair source — •Oleg Nikiforov and Thomas Walther — AG Laser und Quantenoptik, Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

Quantum Key Amplification (QKA) offers information-theoretical security for communication superior to the majority of contemporary classical key distribution and amplification schemes. An entangled photon pair source is being set up for the QKA experiment “Quantum Key Hub“ within the Collaborative Research Center CROSSING at TU Darmstadt.

The energy-time entangled photons at telecommunication wavelengths will be used for entanglement-based QKA protocols and should obtain high coherence length. Therefore transform limited pulses are created at the 1550 nm wavelength using an fiber amplifier [1]. Then, after second harmonic generation in an PPLN crystal, the converted light pulses lead to creation of entangled photon pairs via spontaneous parametric down conversion of type II in a PPKTP crystal [2]. The current experimental status is discussed.

[1] K. Schorstein and T. Walther. “A high spectral brightness Fourier-transform limited nanosecond Yb-doped fiber amplifier”. Applied Physics B 97 (2009), pp. 591-597.

[2] E. Keller, and M. H. Rubin. ”Theory of two-photon entanglement for spontaneous parametric down-conversion driven by a narrow pump pulse“. Physical review. A 56.2 (1997): 1534-1541.

Q 31.50 Tue 17:00 P OGs

An FPGA based detection system for QKA — •Stefan Schürl, Kai Roth, Oleg Nikiforov, and Thomas Walther — AG Laser und Quantenoptik, Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

Quantum Key Amplification (QKA) offers information-theoretical security for communication superior to the majority of contemporary classical key distribution and amplification schemes. Alice and Bob modules are being designed for the QKA experiment “Quantum Key Hub“ within the Collaborative Research Center CROSSING at TU Darmstadt.

In order to evaluate timing statistics of photon pair incidents, we present a modified version of the board designed by J.K.Peters [1]: an inexpensive FPGA-based 4 channel system for timing aquisition of TTL signals with an enhanced timing resolution of under 500 ps. This resolution is achieved by creating additional clocks using built in phase-lock loops. The current experimental status is discussed.

[1] J. K. Peters, S. V. Polyakov, A. L. Migdall, and S. W. Nam, “Simple and inexpensive FPGA-based fast multichannel acquisition board”; https://www.nist.gov/services-resources/software/simple-and-inexpensive-fpga-based-fast-multichannel-acquisition-board (2015).

Q 31.51 Tue 17:00 P OGs

Towards single neutral atoms in crossed fiber cavities — •Dominik Niemietz, Manuel Brekenfeld, Joseph Dale Christesen, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Cavity quantum electrodynamics provides a rich toolbox for the investigation of fundamental phenomena in quantum physics with intriguing applications in quantum information processing. The coupling rate between the cavity light mode and a single emitter, e.g., a neutral atom trapped in the cavity, is inversely proportional to the square root of the mode volume. Limits imposed by traditional manufacturing processes of the cavity mirrors were 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 therefore larger coupling rates, fiber cavities also allow for new cavity geometries due to their smaller dimensions. We are currently setting up a new apparatus consisting of two crossed fiber cavities, coupling independently two light modes to one single atom. This constitutes an important step towards the realization of a spatially and functionally 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] D. Hunger *et al.*, New J. Phys. **12**, 065038 (2010)
[2] M. Uphoff *et al.*, Appl. Phys. B **122**, 46 (2016)

Q 31.52 Tue 17:00 P OGs

Towards cavity-enhanced spectroscopy of single ions in a crystal — •Natalie Wilson, Benjamin Merkel, and Andreas Reiserer — Max Planck Institute of Quantum Optics, Garching, Germany

A future quantum network will consist of quantum nodes that are connected by optical photons, allowing users to perform tasks and interact in ways that are not possible with current technology. In this context, rare-earth-ion doped crystals have recently emerged as a promising platform. In contrast to other impurities, these ions can exhibit telecommunication-wavelength transitions between inner shells which are well-decoupled from the crystal and therefore protected from decoherence. However, because of the narrow linewidth of these transitions, spectrally resolving individual ions is challenging.

In this work, we propose a method to overcome this challenge by embedding rare-earth-ion doped crystals into optical resonators. Because of the Purcell effect, the narrow linewidths will be broadened, and photon emission will efficiently be channelled into the resonator output mode, leading to a dramatically enhanced fluorescence signal. This might enable studies of the crystalline environment of individual ions with the goal to harness them for the implementation of quantum networks and repeaters.

Q 31.53 Tue 17:00 P OGs

Towards quantum optical experiments with silicon vacancy color centers in diamond at millikelvin temperatures — •David Gross, Jonas Nils Becker, Carsten Arend, Pavel Bushev, and Christoph Becher — Fakultät NT (FR Physik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken, Germany

The search for a solid state spin-photon-interface for quantum communication applications allowing for efficient entanglement generation as well as long distance communication is a challenging task. Showing very narrow-band emission and all-optical coherent control, the silicon vacancy center (SiV) in diamond is a promising candidate for such an interface. However, the ground state coherence time of the SiV is limited to 35-45 ns by phonon-mediated processes, whereas pure spin-relaxation times in the millisecond regime have been reported. Therefore, by supressing phonon-induced decoherence, large spin coherence times can potentially be reached, rendering the SiV an ideal system for efficient long-distance quantum communication. We here present design and first experiments with a confocal microscope setup placed in a dilution refrigerator allowing full optical access at temperatures in the mK range. This enables the measurement of the SiV's coherence properties beyond the phonon limited regime and potentially paves the way for future quantum information processing experiments using SiV centers requiring long coherence time scales.

Q 31.54 Tue 17:00 P OGs

RF-Spektroskopie von ^{40}Ca^{+}-Kristallen — •Jens Welzel, Felix Stopp und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Der Zeemangrundzustand $S_{1/2}$ in einfach geladenem Kalzium spaltet in einem homogenen Magnetfeld in die Zustände $m = +\frac{1}{2}$ und $-\frac{1}{2}$ auf. Wir verwenden eine planare Ionenfalle für einzelne gespeicherte Ionen oder Ionenkristalle und arbeiten bei einer Energieaufspaltung der Zeemanzustände von 9,3 MHz. Zunächst wird der Zustand der Ionen durch optisches Pumpen in $m = -\frac{1}{2}$ initalisiert. Radiofrequenz wird nahe der Resonanz eingestrahlt und anschließend der Zustand der Ionen nach einem Transfer von $m = -\frac{1}{2}$ in den metastabilen $D_{5/2}$ Zustand, gefolgt von laserinduzierter Fluoreszenz, nachgewiesen. Wir berichten von Kohärenzmessungen und der Verbesserung der Spinkohärenz durch Echosequenzen. Stromdurchflossene Leiter, integriert in der Ionenfalle, erlauben einen magnetischen Gradienten von $(16,7\pm0,8)\ \frac{\mathrm{T}}{\mathrm{m}}$ in radialer Richtung [1]. Wir beobachten Seitenbandanregungen für einzelne Ionen mit $\eta = (1,2 \pm 0,4)\cdot 10^{-3}$, ebenso wie Seitenbandspektren für lineare Kristalle nahe der Zickzackinstabilität [2].

[1] Welzel, J. et al. Eur. Phys. J. D **65**, 285−297 (2011).
[2] Kaufmann, H. et al. PRL **109**, 263003 (2012).

Q 31.55 Tue 17:00 P OGs

Single trapped ions for Rydberg quantum logic — Patrick Bachor[1,2], •Justas Andrijauskas[1,2], Jochen Walz[1,2] und Ferdinand Schmidt-Kaler[1] — [1]Institut für Physik, Universität Mainz, Staudinger Weg 7, D-55128 Mainz — [2]Helmholtz-Institut Mainz, D-55099 Mainz

The excitation of cold trapped single ions into Rydberg states enables new possibilities in quantum information and non-equilibrium physics. The interplay between Coulomb and Rydberg interactions motivates several proposals for fast multi-qubit gate operations, novel many-body phenomena such as hexagonal plaquette spin-spin interactions, and the driving of fast structural phase transitions in ion crystals.

In our experiment linear crystals made up from ^{40}Ca^{+} ions in a linear segmented Paul trap are used. We excited the $52F$, $53F$ [1] and the $22F$ [2] Rydberg states using a single photon vacuum-ultraviolet excitation near 122.042 nm, 122.032 nm and 123.256 nm wavelengths, respectively. To move towards quantum logic, we recently implemented coherent initialization into different $3D_{5/2}$ Zeeman states, sideband ground state cooling and local addressing of single ions for the excitation into the Rydberg state.

[1] T. Feldker et al., Phys. Rev. Lett. 115 (2015) 173001
[2] P. Bachor et al., J. Phys. B. 49 (2016) 154004

Q 31.56 Tue 17:00 P OGs

Analytical tools for investigating strong-field QED processes in tightly focused laser fields — Antonino Di Piazza and •Alessandro Angioi — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

The computation of QED rates in intense laser fields is typically performed within the plane-wave approximation [1], although the high intensities considered in most calculations are only reachable in planned facilities by tightly focusing the laser energy not only in time but also in space. A novel approach [2], based on the assumption that the energy of the involved charged particles is the largest dynamical energy scale in the problem, allows to relax this hypothesis and paves the way for the calculation of QED processes in fields with generic spatiotemporal structure. Here we will show the practical feasibility of this method for two elementary QED processes, namely nonlinear Breit-Wheeler pair production [3] and nonlinear Compton scattering. The rates for these processes show significant quantitative deviations with respect to the analogous results in a plane wave, and the corresponding results could be important for the design of experiments aiming at measuring these processes.

[1] A. Di Piazza et al., *Rev. Mod. Phys.* **84**, 1177 (2012).
[2] A. Di Piazza, *Phys. Rev. Lett.* **113**, 040402 (2014).
[3] A. Di Piazza, *Phys. Rev. Lett.* **117**, 213201 (2016).

Q 31.57 Tue 17:00 P OGs

Casimir Force and Heat Transfer between Topological Insulators — •Sebastian Fuchs[1], Frieder Lindel[1], Mauro Antezza[2], and Stefan Buhmann[1] — [1]Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [2]Université de Montpellier, Montpellier, France

Due to broken time-reversal symmetry, topological insulators may show very interesting optical properties [1]. This leads to the possibility of switching between an attractive and a repulsive Casimir-Polder potential between a topological insulator and an atom [2]. Motivated by these findings, we investigate theoretically the Casimir pressure between two infinitely extended topological insulators. Moreover, it stands to reason to study the heat transfer for such a setup in case of two different temperatures. Thus we want to establish a connection with a recent study of persistent heat currents between three topological insulators at the same temperature [3].

[1] J. A. Crosse, Sebastian Fuchs, and Stefan Yoshi Buhmann, Phys. Rev. A 92, 063831 (2015)
[2] Sebastian Fuchs, J. A. Crosse, Stefan Yoshi Buhmann, arxiv: 1605.06056
[3] Linxiao Zhu, Shanhui Fan, Phys. Rev. Lett. 117, 134303 (2016)

Q 31.58 Tue 17:00 P OGs

Quantum Friction with Hyperbolic Structures — •Marty Oelschläger[1,2], Francesco Intravaia[1], and Kurt Busch[1,2] — [1]Max-Born-Institut, 12489 Berlin, Germany — [2]Institut für Physik, Humboldt Universität zu Berlin, 12489 Berlin, Germany

One crucial difference between classical and quantum physics is the concept of vacuum, which in the quantum description is not empty but pervaded by roiling fluctuations. These give rise to a plethora of phenomena of which the best known are van der Waals/Casimir-Polder forces. Recently, there has been a resurgent and growing interest in non-equilibrium fluctuation-induced phenomena and in particular in quantum-friction. Unlike the classical case quantum friction does not involve any contact between the objects and the force is mediated by the interaction with the vacuum fluctuations of the quantum electromagnetic field. Importantly, vacuum is not immutable and its structure can be modified with solids and nano-structures. In this work we consider quantum friction between an atom moving at constant velocity parallel to the surface of a hyperbolic material made of alternating metallic and insulating layers. We investigate the behaviour of the frictional force as function of the atomic velocity and of the distance from the surface and compare them with the expressions for the non-structured system. Special attention is paid to the role of widely used treatments based on the Markov, the local thermal equilibrium and/or the effective medium approximation.

Q 31.59 Tue 17:00 P OGs

Atom Position Control — •Karl Nicolas Tolazzi, Christoph Hamsen, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

A strongly coupled single-atom-cavity system is well suited to implement quantum nonlinear optics at the single-photon level. In order to achieve strong coupling with a constant and reproducible coupling strength, the single atom must be well positioned within the cavity mode. In our experiment the atom is held inside the cavity in a three dimensional optical lattice that is formed by a blue-detuned intracavity standing wave together with a blue and a red transverse standing wave. Fluorescence light that is emitted during cooling of the atom is collected by a high numerical-aperture objective and detected on a camera. With a single 2 dimensional (2D) image, the 3D position of the atom can be determined using the out-of-focus blur to assess the out-of-plane direction. This allows for measuring the position and extent of the vacuum cavity mode in three dimensions by probing the atom-cavity coupling via normal-mode spectroscopy and post-selecting on specific atom positions. As the standing waves of the transverse traps are movable due to piezo elements on the retroreflecting mirrors, we are able to control the atom position via feedback. The knowledge of the atom position with respect to the cavity mode and the ability to shift and stabilize its position grant a high and constant coupling strength between them over many experimental cycles and is here shown by reaching an average coupling strength close to the theoretical value.

Q 31.60 Tue 17:00 P OGs

Fiber Fabry-Perot cavities fabrication for cavity quantum electrodynamics experiments — •Michael Kubista, Seyed Alavi, Wolfgang Alt, Jose Gallego, Tobias Macha, Miguel

Martinez-Dorantes, Deepak Pandey, Lothar Ratschbacher, Eduardo Urunuela, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

Fiber Fabry-Perot cavities (FFPC), formed by micro-machined mirrors on the end-facets of optical fibers [1], are used in an increasing number of technical and scientific applications. Here, we present the fabrication process of the micro mirrors and two different approaches to construct FFPC: a piezo-mechanically actuated cavity with feedback based on the Pound-Drever-Hall locking technique and a novel rigid cavity design that makes use of the high passive stability of a monolithic cavity spacer and employs thermal self-locking and external temperature tuning [2]. Furthermore, we discuss effects specific to FFPC such as Raman scattering and asymmetric line shapes. Finally, we present our latest results regarding imaging and strong coupling of small ensembles of 87Rb neutral atoms to one of our fiber cavities.

[1] D. Hunger, et al N. J. Phys. 12, 065038 (2010). [2] Gallego, J. et al. Appl. Phys. B (2016)

Q 31.61 Tue 17:00 P OGs

Excitons in WS2 coupled to a Microcavity — •Christian Gebhardt[1], Michael Förg[1], Hanno Kaup[1,2], Thomas Hümmer[1,2], Hisato Yamagutchi[3], Theodor Wolfgang Hänsch[1,2], Alexander Högele[1], and David Hunger[1,2] — [1]Ludwig-Maximilians Universität München Faculty of Physics, Schellingstr. 4/III, D-80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — [3]Center for Integrated Nanotechnologies, Materials Physics and Applications Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

Two-dimensional atomic crystals of transition metals dichalcogenides have come to be a recent field of interest due to their attractive optoelectronic properties. In the scope of this work we investigate the excitons in monolayer tungsten disulphide (WS2) coupled to a microcavity. Due to high exciton binding energies and a strong oscillator strength it is possible to observe collective strong coupling of excitons and photons at room temperature. In our experiment we use a tunable open-access cavity with one curved mirror and one planar mirror on top of which WS2 is placed. This type of setup allows to control the spatial separation of both cavity mirrors and thus to vary the exciton-photon coupling in situ. Furthermore, the mirrors define a stable, micron-scale cavity mode, which can form a potential for the exciton polaritons and thus lead to interaction effects. We observe polaritons in our setup which show spatial variation of the Rabi splitting energy on the monolayer sheets. We report on the current state of the experiment.

Q 31.62 Tue 17:00 P OGs

Superradiance of Classical Fields via Projective Measurements — •Daniel Bhatti[1,2], Steffen Oppel[1], Ralph Wiegner[1], Girish S. Agarwal[3], 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 — [3]Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078, USA

We study the state evolution of the fields produced by classical sources, when recording intensity correlations of higher order in a generalized Hanbury Brown and Twiss setup [1]. Apart from an offset, we find that the angular distribution of the last detected photon is identical to the superradiant emission pattern generated by an ensemble of two-level atoms in entangled symmetric Dicke states. As a consequence, we demonstrate that the Hanbury Brown and Twiss effect, originally established in astronomy to determine the dimensions or distances of stars, and Dicke superradiance, commonly observed with atoms in symmetric Dicke states, are two sides of the same coin. We show that the phenomenon derives from projective measurements induced by the measurement of photons in the far field of the sources and the permutative superposition of quantum paths identical to those leading to superradiance in the case of single photon emitters [2].

[1] D. Bhatti, et al., Phys. Rev. A 94, 013810 (2016).
[2] R. Wiegner, et al., Phys. Rev. A 92, 033832 (2015).

Q 31.63 Tue 17:00 P OGs

Backwards Master Equation — •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), Leibniz Universität Hannover

The evolution of a quantum system undergoing continuous measurements is governed by the so-called conditional stochastic master equation. Using the past measurement record, it predicts the state of the system at a given time. We develop a method which allows to verify that state by *retrodiction*, using the future measurement record to compute the backwards evolution of the system.

We derive the stochastic backwards evolution equation of a quantum optical system using only basic quantum mechanics. The conditions on the system are very general so as to make the formalism applicable to a wide range of different setups. As an application, we examine how a Gaussian state evolves in a linear system, and compute the backwards equations of motion of its first and second moments. More concretely, we consider a one-dimensional harmonic oscillator under continuous position measurements coupled to a thermal bath. The proposed procedure allows to affirm the presence of desired properties such as entanglement or other non-classical features in a past quantum state, or even its whole density matrix.

Q 31.64 Tue 17:00 P OGs

Wavefront propagation study concerning the influence of non-ideal mirror surfaces inside a split-and-delay unit on the focusability of XFEL-pulses — •Victor Kärcher[1], Sebastian Roling[1], Liubov Samoylova[2], Karen Appel[2], Harald Sinn[2], Frank Siewert[3], Ulf Zastrau[2], and Helmut Zacharias[1] — [1]Westfälische-Wilhelms-Universität Münster, Wilhelm-Klemm Str. 10, 48149 Münster — [2]European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld — [3]Helmholtz-Zentrum für Materialien und Energie, Albert-Einstein-Straße 15, 12489 Berlin

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 $\mathrm{D} = 24\,\mu$m. The influence of wavefront disturbances caused by height- and 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 31.65 Tue 17:00 P OGs

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 Zacharias[1] — [1]Physikalisches Institut, WWU Münster, Wilhelm-Klemm Straße 10, 48149 Münster — [2]Deutsches Elektronen Synchrotron, Notkestraße 85, 22607 Hamburg

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 $-6\,\mathrm{ps} < \Delta t < +18\,\mathrm{ps}$ 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 31.66 Tue 17:00 P OGs

A split-and-delay unit for the European XFEL: Enabling hard x-ray pump/probe experiments at the HED instrument — •Marco Butz[1], Sebastian Roling[1], Karen Appel[2], Stefan Braun[3], Peter Gawlitza[3], Harald Sinn[2], Frank Wahlert[1], Ulf Zastrau[2], and Helmut Zacharias[1] — [1]Physikalisches Institut, WWU Münster, Wilhelm-Klemm Straße 10, 48149 Münster, Germany — [2]2European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany — [3]3Fraunhofer 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 31.67 Tue 17:00 P OGs

A cavity-enhanced single photon source using the silicon vacancy center in diamond — •Julia Benedikter[1,2], Hanno Kaupp[1,2], Christoph Becher[3], Theodor W. Hänsch[1,2], and David Hunger[1,2,4] — [1]Ludwig-Maximilians-Universität München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Universität des Saarlandes, Saarbrücken, Gemany — [4]Karlsruher Institut für Technologie, Karlsruhe, Germany

Single photon sources are an integral part of various quantum information applications, and quantum emitters in the solid state at room temperature appear as a particularly promising implementation. We couple the fluorescence of individual silicon vacancy centers in nanodiamonds to a tunable optical microcavity to demonstrate a single photon source with increased efficiency, higher brightness, and improved spectral purity compared to the intrinsic emitter properties. We use a fiber-based microcavity with a mode volume as small as $3.4\lambda^3$ and a quality factor of 1.9×10^4 and observe an effective Purcell factor up to 9, and lifetime changes by up to 31%, limited by the finite quantum efficiency of the particular emitters studied here. With the availability of improved materials, our achieved parameters predict up to 1GHz single photon rates, and device efficiencies above 90%.

Q 31.68 Tue 17:00 P OGs

Towards single NV centers in nanostructures as probes for optical near fields — •Alexander Meyer, Richard Nelz, Michel Challier, Selda Sonusen, Ettore Bernardi, and Elke Neu — Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken

Single nitrogen vacancy (NV) color centers in nanostructured diamond are photostable dipoles, forming single photon sources. Since the excited state lifetime depends on the environment of the NV, it is possible to detect environmental changes via lifetime imaging. The hereby gathered information reveals the quantum efficiency of NV centers in these nanostructures [1]; a parameter highly crucial for the usability of NV centers as probes for optical near fields. As a way to change the environment and simultaneously measure the excited state lifetime, we use a home-built combination of an atomic-force and a confocal microscope. We here present preliminary results of proof-of-principle experiments to analyze the quantum efficiency of shallow NV centers in single-crystal nanostructures.

[1] Mohtashami and Koenderink, New J. Phys. **15** 043017 (2013)

Q 31.69 Tue 17:00 P OGs

Optical Antennas for Color Centers in Diamond — •Philipp Fuchs[1], Thomas Jung[1], Hossam Galal[2], Mario Agio[2], Xiao-Liu Chu[3], Stephan Götzinger[3], and Christoph Becher[1] — [1]Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken — [2]Universität Siegen, Laboratorium für Nano-Optik, Walter-Flex-Str. 3, 57072 Siegen — [3]Friedrich-Alexander-Universität Erlangen-Nürnberg, Department Physik, 91058 Erlangen

Color centers in diamond, especially the nitrogen and the silicon vacancy center, have become very promising candidates for the implementation of stationary qubits and bright single photon sources. One of the most challenging problems when working with these defects is the low collection efficiency of the photoluminescence photons out of unstructured diamond films. Because of total internal reflection at the diamond-air-interface, this problem cannot be solved simply by using high NA objectives and the collection efficiency is usually limited to a few percent. Here, we show two new approaches to increase this efficiency by precisely controlling the color centers' dielectric environment. The considered structures are based on thin diamond membranes fabricated via reactive ion etching. Combining the thin membrane with a planar antenna structure allows for creation of tailored radiation patterns, leading to a high directivity and thereby high collection efficiency for all emitters in the membrane at the same time. A radiating dipole in such structures can be calculated analytically, which allows for computer-aided optimization of the structure.

Q 31.70 Tue 17:00 P OGs

Nanofabrication of Optimized Diamond Scanning Probe — •Michel Challier[1], Richard Nelz[1], Philipp Fuchs[1], Julia Purtov[2,3], Ettore Bernardi[1], Selda Sonusen[1], René Hensel[3], and Elke Neu[1] — [1]Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken — [2]Universität des Saarlandes, Fakultät NT - Fachrichtung Materialwissenschaft und Werkstofftechnik, Campus E1.3, 66123 Saarbrücken — [3]INM - Insititut für neue Materialien GmbH, Campus D2.2, 66123 Saarbrücken

Nitrogen vacancy (NV) color centers in diamond represent highly-coherent, atomic-sized spin systems with optical spin read-out and photostable fluorescence. To harness their full potential as magnetic and near field sensors, single NVs have to be incorporated into nanophotonic structures. We focus on fabricating scanable single crystalline diamond nanowires on thin ($< 1\,\mu$m) platforms generating probes with high spatial resolution and NV fluorescence. Using numerical methods, we optimized the pillar shapes. Thin membranes, platforms and pillars are created using inductively coupled plasma reactive ion etching, direct laser writing lithography and electron beam lithography. We optimize all process steps in comparison to previous work [1].

[1] Patrick Appel, Elke Neu, Marc Ganzhorn, Arne Barfuss, Marietta Batzer, Micha Gratz, Andreas Tschöpe and Patrick Maletinsky, Rev. Sci. Instrum. 87, 063703 (2016)

Q 31.71 Tue 17:00 P OGs

Robust Silicon-Vacancy Single Photon Sources — •Assegid Mengistu Flatae[1,2], Francesco Tantussi[2], Stefano Lagomarsino[1], Gabriele Messina[2], Hossam Galal[1], Ahmad Mohammadi[3], Francesco De Angelis[2], and Mario Agio[1] — [1]Laboratory of Nano-Optics, University of Siegen, 57072 Siegen, Germany — [2]Italian Institute of Technology, 16163 Genova, Italy — [3]Department of Physics, Persian Gulf University, 75196 Bushehr, Iran

In quantum information science and in fundamental quantum optics a robust narrow-band solid-state single-photon source is desirable. We currently develop techniques for the fabrication and optical characterization of single photon-sources based on the silicon vacancy (SiV) in diamond. SiV color centers are promising candidates as most of the fluorescence signal is concentrated in a narrow zero-phonon line at 738 nm, with a room temperature line-width down to about - 1 nm. In addition, the center exhibits a short excited-state life-time (~ 1 ns) and a very small inhomogeneous broadening. The photonic environment around the single SiV color center can be exploited to control the radiative rate, the quantum efficiency, the angular distribution and the polarization of the emitted photons. Plasmonic gold nano-antennas are particularly interesting for these purposes, as they can achieve a much smaller mode volume in the confined near field (~ 7 orders of magnitude tighter than solid-state micro-cavities) and can easily match the emission wavelength of the emitter due to their broad Plasmon resonances. We design, fabricate and characterize gold nano-antennas for enhancing the emission properties of Siv color centers.

Q 31.72 Tue 17:00 P OGs

Optical investigation of color centers in nanodiamonds — •Andrea Kurz[1], Olaf Zimmermann[1], Valery Davydov[2], Viatchselav Agafonov[3], Lachlan Rogers[1], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Institute for High Pressure Physics, Russian Academy of Science, Moscow, Russia — [3]Greman, Université F. Rabelais, Tours, France

Over the last decade color centers in diamond have proven to be promising candidates for quantum optics applications [1]. For applications like sensing or cQED it is advantageous to use color centers in nanodiamonds (NDs). However these color centers often exhibit inferior optical qualities compared to bulk diamonds. Although for example spectral properties for silicon vacancies centers have recently been improved dramatically [2], issues like blinking and spectral defusion remain.

Therefore investigating the optical properties for color centers in NDs is an important goal. We are testing methods to increase their optical and coherence properties. The analysis is done with confocal spectroscopy at room and cryogenic temperatures. In the future we aim to incorporate these color center in NDs into cQED experiments.

[1] F. Jelezko, J. Wrachtrup, Phys. Stat. Sol. 203, Issue 13, 2006

[2] U. Jantzen et. al., NJP, Vol. 18, 2016

Q 31.73 Tue 17:00 P OGs

Double-resonant Cavity-enhanced Raman Spectroscopy of Carbon Nanotubes — •Thomas Hümmer[1,2], Theodor W. Hänsch[1,2], and David Hunger[3,1,2] — [1]Ludwig-Maximilians-Universität München, Deutschland — [2]Max-Planck Institut für Quantenoptik, Garching, Deutschland — [3]Karlsruher Institut für Technologie, Karlsruhe, Deutschland

We use a tunable high-finesse optical microcavity[1] to demonstrate Purcell enhancement of Raman scattering in combination with high-resolution scanning-cavity imaging[2]. We detect cavity-enhanced Raman spectra[3] of individual single-walled carbon nanotubes and co-localize measurements with cavity-enhanced absorption microscopy. By using a double resonance of the cavity, where both the excitation light and the Raman-scattered light is simultaneously resonant with a high finesse cavity mode, we expect signal enhancements by four orders of magnitude. We report on the current status of the experiment and explain it with the help of free candy.

[1] Hunger et al., NJP 12, 065038 (2010) [2] Mader et al., Nat Commun 6, 7249 (2015) [3] Hümmer et al Nat Commun 7, 12155 (2016)

Q 31.74 Tue 17:00 P OGs

A supercontinuum source in the extreme ultraviolet using HHG with an OPA system — •Julius Reinhard[1], Martin Wünsche[1,2], Silvio Fuchs[1,2], Jan Nathanael[1,2], Jakob Abel[1], Christian Rödel[1,3], and Gerhard Paulus[1,2] — [1]Institute of Optics and Quantum Electronics, Friedrich-Schiller-University Jena, Germany — [2]Helmholtz Institute Jena, Germany — [3]SLAC, USA

We present a supercontinuum source in the extreme ultraviolet (XUV) using high harmonic generation (HHG) driven by a table-top femtosecond laser and a tunable optical parametric amplifier. The near-infrared (NIR) pulses from the OPA generate the harmonic radiation. Usually the spectrum of the HHG is a comb with maxima at the odd multiples of the fundamental frequency. By averaging over different harmonic comb spectra with slightly different fundamental frequencies a continuous XUV spectrum in the range of 30 to 200 eV is realized [1]. For this, the driving laser wavelength from the OPA is swept automatically during the recording of the XUV spectrum and the supercontinuum is generated within a few seconds. The supercontinuum XUV source with a photon flux up to 3×10^8 photons per eV's is well suited for applications like near-edge absorption fine structure spectroscopy (NEXAFS) [2] or XUV coherence tomography (XCT) [3] and marks an important step for realizing such applications in small-scaled laboratories.

[1] M. Wünsche et al., Optics Express, submitted (2016)

[2] J. Stöhr, NEXAFS spectroscopy, Springer Series in Surface Science, Vol. 25 (2013)

[3] S. Fuchs et al., Scientific Reports 6, 20658 (2016)

Q 31.75 Tue 17:00 P OGs

Picosecond Fiber Amplifiers in a MOPA System for Laser Cooling of Relativistic Ion Beams — •Daniel Kiefer, Christian Kühnel, and Thomas Walther — TU-Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstr. 7, 64289, Darmstadt

Laser cooling of relativistic ion beams has been demonstrated and shown to be a sophisticated technology with achievable low relative momentum spreads [1]. White-light-cooling was proposed as a method to help minimize particle loss due to intra beam scattering (IBS) processes [2] and has been demonstrated for fast stored ion beams [3]. To obtain the required spectral width for laser cooling of relativistic ion beams at GSI (ESR) and FAIR (SIS100, HESR), we plan to use pulsed laser light. A cw MOPA system in combination with acousto-optical and electro-optical modulation provides laser pulses of 50 ns or 70 to 740 ps with a center wavelength of 1030 nm [4]. An efficient fourth harmonic generation process to 257.5 nm demands high peak intensities. Two cascaded fiber amplifiers are used to enhance the energy of the pulses. The setup is chosen so that the amplifier stages work properly for the different pulse lengths covering three orders of magnitude. We show the performance of the amplifiers with regard to power and spectrum. Furthermore, the current status of the experiment will be presented. [1] U. Schramm et al, Proceedings of (2005) Particle Accelerator Conference [2] R. Calabrese, Hyperfine Interactions 99, 259-265, (1996) [3] S. N. Atutov et al, Phys. Rev. Lett. 80, 2129, (1998) [4] D. Kiefer et al, GSI Scientific Report 2015, DOI:10.15120/GR-2016-1

Q 31.76 Tue 17:00 P OGs

SHG in Periodically Poled Lithiumniobate for a CW Laser System used for Cooling of Relativistic Ion Beams — •Sebastian Klammes, Daniel Kiefer, and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstr. 7, 64289 Darmstadt

Laser cooling has become an additional method for increasing the phase space density of ion beams in storage rings [1]. In order to reduce the emittance of the circulating ion beam, suitable conditions must be fulfilled, e.g. radiation of a specific wavelength and an appropriate power must be provided. To this end a fast tunable cw laser system with two SHG enhancement cavities has been developed in the past to achieve the correct wavelength for ion beam cooling [2]. In 2012, the cw laser system was successfully used for cooling C^{3+}-ions [3]. Further developments of the cw laser system led to the replacement of the first enhancement cavity with a magnesium oxide doped periodically poled $LiNbO_3$ (MgO:PPLN) crystal. Observations and experiences with the MgO:PPLN crystal will be presented. Additionally, the latest results and the current status will be featured. [1] U. Schramm and D. Habs. Crystalline ion beams. Progress in Particle and Nuclear Physics 53 (2004), 583-677. [2] T. Beck, B. Rein, F. Sörensen and T. Walther. Solid-state-based laser system as a replacement for Ar^+ lasers. Opt. Lett. 41, 4186-4189 (2016) [3] T. Beck. Lasersystem zur Kühlung relativistischer C^{3+}-Ionenstrahlen in Speicherringen. Dissertation. TU Darmstadt (2015).

Q 31.77 Tue 17:00 P OGs

Spektroskopie von Nd^{3+}-, Ho^{3+}- und Tm^{3+}-dotierten Sesquioxiden im mittleren infraroten Spektralbereich — •Patrick von Brunn[1,2], Alexander M. Heuer[1,2] und Christian Kränkel[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging

Laser im mittleren infraroten Spektralbereich sind aufgrund ihrer starken Absorption in Wasser hervorragend geeignet für medizinische Anwendungen, die eine hohe Präzision erfordern. Seltenerd-dotierte Sesquioxide eignen sich besonders als aktive Materialien für derartige Laser. Ihre geringe Phononenenergie führt zu niedrigen nichtstrahlenden Zerfallsraten und ihre hohe Wärmeleitfähigkeit ermöglicht Laserbetrieb bei hohen Ausgangsleistungen. Hier berichten wir über die spektroskopische Analyse verschiedener Seltenerd-dotierter Sesquioxide bis in den mittleren infraroten Spektralbereich. Für Nd^{3+}-, Ho^{3+}- bzw. Tm^{3+}-dotiertes Lu_2O_3 wurden die Absorptionswirkungsquerschnitte und Fluoreszenzspektren sowie die Lebensdauern der beteiligten angeregten Niveaus bestimmt. Die Absorptionswirkungsquerschnitte wurden für Ho^{3+}- und Tm^{3+}-dotiertes Lu_2O_3 im zum optischen Pumpen geeigneten Wellenlängenbereich von 400 nm bis 2200 nm bestimmt. Für die Emissionsmessungen wurde das Messintervall auf den Wellenlängenbereich bis 4,4 μm ausgeweitet. Die Resultate weisen auf potentielle Laserübergänge im Bereich von 4,1 μm und 2,9 μm für Ho^{3+}:Lu_2O_3 sowie 2,6 μm für Tm^{3+}:Lu_2O_3 hin; entsprechende Laserexperimente sind in Planung.

Q 31.78 Tue 17:00 P OGs

Two-color spectroscopy for laser stabilization to the ytterbium 1S0-3P1 intercombination line — •Laura Sucke, Christian Halter, Tobias Franzen, Bastian Pollkesenser, Mustafa Jumaah, Cristian Bruni, and Axel Görlitz — Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Deutschland

We present a scheme for frequency stabilization of multiple lasers that are resonant with different transitions and originating from a common ground state. For the detection of weaker transitions we are harnessing the high signal to noise ratio provided by a strong transition. Doppler reduced spectroscopy is performed on an atomic beam by detecting the fluorescence of a strong dipole allowed transition. Individual error signals for this transition as well as additional weaker transitions are recovered from the strong fluorescence signal using lock-in techniques. We demonstrate the application to the strong 1S0-1P1 transition and the 1S0-3P1 intercombination line of ytterbium. We show data on the stability of this locking technique by comparing two identical spectroscopy setups

Q 31.79 Tue 17:00 P OGs

The Gauss-Newton algorithm for light scattering on transparent cylinders — •Gunnar Claussen[1,2], Werner Blohm[1], and

Armin Lechleiter[2] — [1]Fachbereich Ingenieurwissenschaften, Jade Hochschule Wilhelmshaven Oldenburg Elsfleth — [2]Zentrum für Technomathematik, Universität Bremen

We aim to determine the diameter of a glass fiber under perpendicular incidence of plane-wave light and treat this question as an inverse scattering problem, which is solvable through an iteratively regularized Gauss-Newton algorithm. Within each step of the algorithm, the expression $||F'[q_n^\delta]h_n + F(q_n^\delta) - u_\infty^\delta||_{L^2}^2 + \alpha_n||h_n + q_n^\delta - q_0||_s^2$ is minimized. This term includes the measured far-field pattern u_∞^δ, the data-to-pattern operator $F(\cdot)$, i.e. the formalism given by the Mie theory for cylinder scattering, and its Fréchet derivate $F'(\cdot)$, the parameter vector q_n^δ and its alteration h_n within the current step of the iteration. The algorithm terminates once the residual $||F(q_n^\delta) - u_\infty^\delta||$ becomes sufficiently small. However, it turns out that for transparent cylinders the residual forms a complex "landscape" in the parameter-space that is characterized by a number of false minima, thereby hindering the correct execution of the algorithm. We introduce a novel variation of the Gauss-Newton algorithm which allows us to skip these minima in order to reach the global minimum, allowing us to determine the cylinder diameter with a precision several magnitudes smaller than the incident wavelength λ. We will present the performance of this algorithm in terms of precision, running time, experimental applicability and tolerance towards variations of fixed parameters.

Q 31.80 Tue 17:00 P OGs

Brillouin-LIDAR zur Messung von Temperaturprofilen im Ozean — •David Rupp[1], Sonja Friman[1], Andreas Zipf[1], Charles Trees[2] und Thomas Walther[1] — [1]TU Darmstadt, Institut für Angewandte Physik, 64289 Darmstadt — [2]CMRE, 19126 La Spezia, Italien

Wir entwickeln ein flugtaugliches LIDAR-System zur Messung von Wassertemperaturen im Ozean. Das LIDAR-System soll es ermöglichen, Temperaturprofile bis zu 100 m Tiefe bei einer Ortsauflösung von 1 m in quasi Echtzeit zu ermitteln. Mit Hilfe von mehreren Faserverstärkerstufen erzeugte Laserpulse mit einer Pulsdauer von 10 ns und einer Repetitionsrate von 1 kHz werden frequenzverdoppelt, sodass das ins Wasser eingestrahlte Licht dann eine Wellenlänge von 543 nm hat, abgestimmt auf den Detektor. Die Temperaturinformation wird aus der spektralen Verschiebung des rückwärtig Brillouin-gestreuten Lichts gewonnen. Der Detektor besteht im Wesentlichen aus einem atomaren Absorptionsfilter, der das elastisch gestreute Licht eliminiert und einem atomaren Kantenfilter (ESFADOF), beide auf Rubidium basierend. Der Kantenfilter hat eine von der spektralen Verschiebung abhängige Transmission, welche gemessen und einer Temperatur zugeordnet wird. Im Labor wurde die Funktion des Systems bereits demonstriert und bei einem ersten Feldtest untersucht. Die Funktionsweise des Systems, einige Ergebnisse, bereits durchgeführte und zukünftige Verbesserungen werden vorgestellt.

Q 31.81 Tue 17:00 P OGs

Untersuchung spektraler Eigenschaften von Brillouin-Streuung in Abhängigkeit von Temperatur und Salzgehalt in Wasser — •Andreas Zipf, David Rupp, Julius Wessolek und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, 64289 Darmstadt

Kontaktlose und ressourcenschonende Methoden zur Messung von Temperaturprofilen des Ozeans und dessen Salinität sind mittels LIDAR möglich. Die Anwendung der Systeme vereinfacht die Datenakquise unter Meeresbiologen, Ozeanographen und Meteorologen. In unserer Arbeitsgruppe wird hierfür zur Zeit an einem System gearbeitet, das mit Hilfe von Brillouin-Streuung beide Messparameter in bis zu 100 m Tiefe ortsaufgelöst ermitteln kann. Hierzu wird ausgenutzt, dass sowohl die spektrale Verschiebung, als auch die spektrale Breite der Brillouin-Streuung von Temperatur und Salzgehalt abhängen.

Insbesondere ist dabei die genaue Kenntnis dieser Abhängigkeiten von Bedeutung. In einem selbst angefertigten Test-Aufbau werden Daten der Brillouin-Streuung bei 530 nm an Wasser verschiedener Salzgehalte gewonnen und mit Hilfe eines Fabry-Perot-Interferometers näher untersucht. Ziel ist es, mit Hilfe der gewonnenen Daten die Entwicklung einer zuverlässigen Detektoreinheit für den gepulsten Betrieb bei 543 nm zu erleichtern.

Aufgezeigt werden die aktuellen Erkenntnisse sowie die nächsten Entwicklungsschritte.

Q 31.82 Tue 17:00 P OGs

Generation and characterization of tunable and shapeable few-optical-cycle mid infrared pulses — •Daniel Gerz[1], Nick Paul[1], Cristian Manzoni[2], Giulio Cerullo[2], and Marcus Motzkus[1] — [1]PCI, Ruprecht-Karls-Universität, D-69120 Heidelberg, Germany — [2]Dipartimento di Fisica, Politecnico Milano, I-20133 Milano, Italy

The generation of short (<20fs), broadband, mid infrared (MIR) pulses in a robust manner still remains a significant challenge in various spectroscopic fields. Such pulses can be utilized for a number of different applications, including sub-gap electronic states and coherent control of small molecules. In order to promote major advancements in such fields, development of new, easy to use MIR sources is a must.

In this work, we present a two stage non-collinear parametric amplifier to be used for the generation of few-optical-cycle pulses with center wavelengths ranging from 2.9-3.3 μm and powers in the order of few μW [1].These pulses are then compressed and shaped using a germanium based acousto-optic modulator shaper. The aim is to readily shape such pulses into multipulse sequences which could be applied in multidimensional IR spectroscopy, or as a source of precisely tailored MIR push/dump pulses for 1D 3^{rd} order (or higher) spectroscopies [2]. The pulse characterization is performed with a cross-correlation frequency resolved optical gating (XFROG) setup, which upconverts the MIR into the visible regime for easy and accurate detection.

[1] Brida, D. et al., Opt. Lett. 33, 2901-2903 (2008).
[2] Shim, S.-H. et al., Phys. Chem. Chem. Phys. 11, 748-761 (2008).

Q 31.83 Tue 17:00 P OGs

Selektives Ätzen fs-lasergeschriebener 3D-Mikrostrukturen in kristallinem Y3Al5O12 — •Kore Hasse[1,2], Christian Kränkel[1,2] und Thomas Calmano[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg

Mittels fs-Laserstrukturierung ist es möglich 3D-Materialmodifikationen in der Größenordnung von wenigen μm in transparenten dielektrischen Materialien zu erzeugen. Zudem ist die Ätzrate fs-lasermodifizierter kristalliner Materialien wie Y3Al5O12 (YAG) in Phosphorsäure deutlich höher als diejenige des unstrukturierten Materials. Daher können durch fs-Laserstrukturierung und nachfolgendes Ätzen Mikrokanäle in Kristallen wie YAG hergestellt werden, die in mikrofluidischen und optischen Systemen Anwendung finden können. Wir berichten über die Ergebnisse einer systematischen Untersuchung der Ätztiefe in Abhängigkeit von der Ätzdauer in H3PO4 (85%) von fs-lasergeschriebenen Einzelspuren in [111] orientiertem YAG. Dabei wurden sowohl der Einfluss der Strukturierungsparameter, wie auch derjenige der Temperatur der Säure untersucht. Mit durchschnittlichen Ätzraten von bis zu 2,6 μm/h konnten mehr als 4 mm lange Mikrokanäle mit einem Aspektverhältnis (Länge zu Durchmesser) von bis zu 400 geätzt werden.

Q 31.84 Tue 17:00 P OGs

Study of electron photoemission from a tungsten nanotip triggered by ultrashort laser pulses with photon energies from UV to mid-IR — •Ang Li, Martin Kozak, Joshua McNeur, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen

Electron photoemission from metallic nanotips is employed in various applications that require high brightness bunched electron beams. Such applications include ultrafast electron microscopy and diffraction [1] as well as the operation of dielectric laser accelerators [2]. The latter is based on micron-scale dielectric nanostructures driven by the high peak field of short laser pulses and has been experimentally demonstrated [3,4]. This acceleration technique requires excellent electron beam quality in order to obtain an efficient acceleration without high losses of electron current. In this contribution we report on a recent experimental study of electron photoemission from tungsten nanotips triggered by the ultrashort laser pulses with photon energies ranging from UV to mid-IR. Further, the observation of transition between single- and multiphoton photoemission is discussed along with the regime of light-induced tunneling process. We focus on the role of Coulomb repulsion in the regime of more than one emitted electron per laser pulse.

[1] A. H. Zewail et al., 4D Electron Microscopy: Imaging in Space and Time (Imperial College Press, London, 2010).
[2] J. England et al., Rev. Mod. Phys. 86, 1337 (2014).
[3] J. Breuer et al, Phys. Rev. Lett. 111, 134803 (2013).
[4] E. A. Peralta et al., Nature 503, 91-94 (2013).

Q 31.85 Tue 17:00 P OGs

Controlling metal nanotip shapes for application in laser triggered electron emission via dynamic electrochemical etching — •Philipp Hofmann, Alexander Tafel, Jürgen Ristein, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen

Ultra sharp tips are essential for nanometer probe techniques such as scanning tunneling microscopy (STM) and are powerful tools for studying strong field physics due to field enhancement at the tip apex. Simulations [1] have shown that large opening angles of approximately 15° for gold and 40° for tungsten nanotips result in maximum optical field enhancement. Static two electrode etching setups, widely used for their simplicity, lack reproducibility and the tip opening angle cannot be influenced. Additionally, important process parameters such as temperature and etching potential are not accurately controlled. In our new setup, an Arduino Mega 2560 regulates and monitors all relevant etching parameters. The electrochemical potential is measured by a reference electrode and the tip shape can be influenced with a dynamic mechanism. Our setup, tested with tungsten, is designed to be easily adoptable to a wide range of tip materials.

[1] Sebastian Thomas et al., 2015 New J. Phys. 17 063010.

Q 31.86 Tue 17:00 P OGs

Towards a PDC source at NIR wavelengths in a single-mode Rb:PPKTP waveguide — •Christof Eigner, Laura Padberg, Matteo Santandrea, Raimund Ricken, Helge Rütz, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Parametric down conversion (PDC) is a well-established process for the generation of non-classical states and single photons. Especially PDC sources that emit in the visible and near-infrared (NIR) are highly attractive for quantum cryptography due to the possibility of low cost Silicon avalanche detection as well as possible coupling to ion traps. Realizing such a source in periodically poled potassium titanyl phosphate (PPKTP) waveguides permits to deploy high pump intensities because of the high damage resistance of the material and at the time allows to harness the potential of integrated optical circuitry.

Producing the rubidium exchanged PPKTP waveguides ourselves allows us to tailor the waveguide properties and apply specifically designed poling patterns. Here, we discuss our approach to manufacture single-mode waveguides in KTP in the NIR at 800 nm. Moreover, we present the current status of our PDC source for the generation of photon pairs in this wavelength regime.

Q 31.87 Tue 17:00 P OGs

Performance improvement of an SPDC source using time-multiplexing — •Marcello Massaro, Harald Herrmann, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Spontaneous Parametric Down-Conversion (SPDC) sources are widely used in quantum optics to produce single photon states used in various experiments and quantum information protocols. One major limitation of such sources is the noise due to multi-photons contributions when one tries to pump them in order to increase the generation rate. These sources are also limited intrinsically due to the physical process that governs them.

We show here that is possible to improve the performance of such sources by using a time-multiplexing scheme or a feed-forward protocol, in order to push the production rate towards the physical limit or even overcome it completely.

Q 31.88 Tue 17:00 P OGs

Weak meassurement of a rotated mode function — •Sabrina Hartmann, Joachim Fischbach, and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

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. We can then postselect photons at the output via polarization and identify a weak value in the correlation function of first order. This allows us to weakly measure the angle, by which the mode function was rotated. Furthermore, we evaluate this interferometric set-up for specific non-classical states.

[1] O.S. Magaña-Loaiza, M. Mirhosseini, B. Rodenburg and R.W. Boyd, *Physical Review Letters*, **112**, 200401 (2014).

Q 31.89 Tue 17:00 P OGs

Towards a feedbacked down-conversion source for large complex quantum states — •Melanie Engelkemeier, Regina Kruse, Linda Sansoni, Sonja Barkhofen, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

In order to realise large photonic quantum states in large networks, we implement a PDC source in a feedback loop to generate time-multiplexed states. By the stimulated generation of photons, the probability to generate photon pairs is increased. We present the source design of a periodically poled KTP crystal [1] and simulations of the setup to outline losses and the stimulation in the system. Furthermore, we will investigate the possibilities to generate complex time-bin correlated states.

[1] Harder, et al., Opt. Exp. 21, 13975-13985 (2013)

Q 31.90 Tue 17:00 P OGs

Quantum signatures in time-domain interferometry — Salvatore Castrignano and •Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The aim of this project is to improve an interferometric scheme proposed in 1997 by A. O. Baron [1]. In this scheme a sample to be studied is placed between two radiation-filtering foils and X-ray radiation, resonant with the Mössbauer nuclei transition, impinges on the whole system. The analysis of sample's internal dynamics is possible through detection of the scattered radiation , in particular the Fourier transform S(q,t) of the dynamical couple-correlation function for the sample G(r,t) can be obtained.

The latter function is a real or complex valued function according to the classical or quantum nature of the measured dynamics [2][3]. Therefore some variations of Baron's scheme are proposed which in principle allow to spot the presence of an imaginary part in the function G(r,t).

Moreover the interferogram in the case of a generic quantum target is derived in a fully quantum frame. In particular the dynamics of a bosonic system subject to a double well potential trap is analysed in order to understand what is the meaning of such Im G(r,t) and what kind of information about the quantum state of the system can be extracted out of it.

[1] Phys. Rev. Lett. 79, 2823
[2] Phys. Rev. 95, 249
[3] Physica 24, 404

Q 31.91 Tue 17:00 P OGs

Velocity Distribution Compression for Electron Beams with Laser Fields — •Moritz Carmesin[1], Maxim A. Efremov[1], and and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [2]Texas A & M University Institute for Advanced Study (TIAS), Institute for Quantum Science and Engineering (IQSE), and Department of Physics and Astronomy, Texas A & M University, College Station, Texas 77843-4242, USA

Various applications such as electron microscopy or the free-electron laser require electron beams with a narrow velocity distribution. In order to control its width, we suggest to use the scattering of the electrons off two counter-propagating light waves generating a one-dimensional ponderomotive potential.

Within non-relativistic classical mechanics, we find that it is indeed impossible to decrease the width of a homogeneous distribution of the initial positions. In contrast, it is possible to compress the velocity distribution for an electron beam with a modulated initial distribution.

This work is supported by the German-Israeli Cooperation (DIP). W.P.S. is grateful to Texas A&M University for a Texas APM University Institute for Advanced Study (TIAS) Faculty fellowship.

Q 31.92 Tue 17:00 P OGs

Multi-Photon Information Processing — •Johannes Seiler[1] and Vincenzo Tamma[2] — [1]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany — [2]University of Portsmouth, Portsmouth, PO1 3QL

We propose a new approach towards quantum information processing using multi-photon interferometers with thermal as well as non-classical light sources. The emergence of a second-order interference effect which takes advantage of the correlation between specific interferometer paths with each other is demonstrated in [1]. This effect could be experimentally useful for simulations of small-scale quantum circuits and applications in high-precision metrology and imaging. Furthermore, we present a general formalism to describe the correlation function of an arbitrary multi-photon interferometer. The obtained structure allows an interpretation in terms of bipartite graphs, giving both a great insight into the physics of such setups, as well as enabling reverse engineering of those.

[1] V. Tamma and J. Seiler, *New J. Phys.* 18(3):032002, 2016

Q 31.93 Tue 17:00 P OGs

Integration of photonic structures and thermal atomic vapors — •Robert Löw[1], Ralf Ritter[1], Harald Kübler[1], Nico Gruhler[2], Wolfram Pernice[3], and Tilman Pfau[1] — [1]5. Physikalisches Institut und IQST, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen — [3]Institute of Physics, University of Münster, Heisenbergstr. 11, 48149 Münster

The usage of atomic vapors in technological applications has become increasingly relevant over the past few years. They are utilized e.g. in atomic clocks, magnetometers, frequency references or to slow down and store light. Integrated devices which combine photonic structures and thermal atomic vapors on a chip could be an ideal basis for such purposes as they provide efficient atom-light coupling on a miniaturized scale. Furthermore, the existing fabrication technology of photonic circuits allows for complex networking and multiplexing designs, potentially even at the single photon level. We report on the status of our work on various photonic structures integrated into a rubidium vapor cell. Specifically, we present our results on combining the atomic medium with Mach Zehnder interferometers [1], ring resonators [2] and slot waveguides. As the atoms are probed in close proximity to the dielectric material, atom-surface interactions and transit time effects play a substantial role.

[1] R. Ritter et al., Appl. Phys. Lett. 107, 041101 (2015).
[2] R. Ritter et al., New J. Phys. 18 103031 (2016).

Q 31.94 Tue 17:00 P OGs

Loading Chromophores into Thin Film Metal Organic Frameworks: Guest-Born Carboxylic Groups Facilitate Dye Incorporation. — •Nicolò Baroni[1], Andrey Turshatov[1], Michael Oldenburg[1], Michael Adams[1], Alexander Welle[2], Engelbert Redel[2], Christof Wöll[2], Bryce S. Richards[1,3], and Ian A. Howard[1] — [1]IMT, KIT, Eggenstein-Leopoldshafen — [2]IFG, KIT, Eggenstein-Leopoldshafen — [3]LTI, KIT, Karlsruhe

Imparting optoelectronic function to surface-anchored metal-organic framework (SURMOF) thin films by loading guest molecules into their porous structures expands the portfolio of applications for which these materials are relevant. In this study, we examine the loading behavior of porphyrin dyes in the SURMOF-2 structures based on Zn metal centers and 1,4-benzenedicarboxylate linkers. Loading is attempted for porphyrin dyes metallated with Pd, Pt, and Zn. For each metalation, the loading behavior of dyes with and without carboxylic pendant groups is compared. The loading procedure is a simple drop-casting, followed by rinse after drying to remove surface-deposited dyes. Using time of flight second ion mass spectroscopy, we demonstrate that the dyes with carboxylic pendant groups penetrate through the whole SURMOF film. We also present a study of the optical properties of the SURMOFs incorporating the guest porphyrin dyes. Examining the steadystate, timeresolved, absorption and emission properties of the system, we find that the guest molecules can interact within the pores leading aggregate behavior to dominate the optical properties. Also,a longlived emission from the unloaded SURMOF itself is observed.

Q 32: Quantum Information: Concepts and Methods V

Time: Wednesday 14:30–16:15 Location: P 2

Q 32.1 Wed 14:30 P 2

Fluorescence state detection of single atoms on a non-cycling transition — •Bo Wang, Matthias Körber, Stefan Langenfeld, Olivier Morin, Andreas Neuzner, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748, Garching, Germany

State-selective fluorescence is widely used to readout the internal state of atoms or ions. Applications range from optical clocks to quantum information processing. To reach a high accuracy, many scattered photons are required. Any loss channel leading to a dark state stops the fluorescence and reduces the fidelity. Therefore, standard fluorescence detection is only applicable for a few internal states that can be excited via a cycling transition, like the $\left|^5S_{1/2},\ F=2\right\rangle$ state in ^{87}Rb. We now theoretically and experimentally study schemes for the detection of the $\left|^5S_{1/2},\ F=1\right\rangle$ state in ^{87}Rb for which a cycling transition does not exist. Our schemes are based on cavity-enhanced fluorescence and alternating probe-beam configurations. By optimizing the control sequence, we currently achieve a hyperfine-state-detection fidelity of 96% in 12 μs. Theoretical concepts for further optimization will be presented.

Q 32.2 Wed 14:45 P 2

Quantum Imaging with Incoherent Light From a Free-Electron Laser — •Raimund Schneider for the Quantum Imaging Collaboration — Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen — Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg — Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

We report on a new method to reconstruct an unknown geometry of independent thermal sources radiating at VUV wavelengths. Our imaging algorithm is based on measuring higher order spatial intensity correlations allowing to extract structural information about the source distribution from the light field even though the sources emit completely incoherently. We present experimental results of imaging an artificial molecule where the atoms are mimicked by holes in a SiN membrane. The hole mask is illuminated by incoherent light scattered from a diffusor which itself is illuminated by the beam of the free electron laser FLASH at DESY, Hamburg. This imaging method is of particular interest in the x-ray regime as the coherence of high energy photons is easily lost, e.g., due to imperfect beam optics or incoherent scattering processes.

Q 32.3 Wed 15:00 P 2

Detection of quantum correlations without quantum discord — •Semjon Köhnke, Elizabeth Agudelo, Melanie Mraz, Oskar Schlettwein, Werner Vogel, and Boris Hage — Institut für Physik, Universität Rostock, Germany

Currently a variety of different nonclassicality criteria are discussed. They should classify whether a quantum state has a classical character or is governed by quantum phenomena.

For testing nonclassicality criteria phase diffused squeezed states were successfully used [1]. These states are a mixture of squeezed states with a stochastically distributed phase. In our experiment we go a step further. We produce an entangled state out of two squeezed fields which interfere on a 50/50 beam splitter. Using phase diffusion at one of the outputs gives us a fully randomized phase relation between both of them. Thereby the entanglement gets destroyed.

To identify quantum correlation effects the quantum discord is widely spread as universal indicator. Though this indicator fails and does not reveal the nonclassical correlations from our experiment. In contrast using the sampling formula of the regularized Glauber-Sudarshan P function [2] we obtain a quasiprobability distribution which uncovers any quantum correlations, going beyond quantum entanglement and quantum discord.

[1] Schnabel et al., Phys. Rev. A 79, 022122 (2009).
[2] Vogel et al., Phys. Rev. A 87, 033811 (2013).

Q 32.4 Wed 15:15 P 2

Entanglement and coherence in quantum state merging — •Alexander Streltsov[1,2], Eric Chitambar[3], Swapan Rana[1], Manabendra Nath Bera[1], Andreas Winter[4,5], and Maciej Lewenstein[1,5] — [1]ICFO, ES-08860 Castelldefels, Spain — [2]Freie Universität Berlin, D-14195 Berlin, Germany — [3]Southern Illinois University, Carbondale, Illinois 62901, USA — [4]Universitat Autònoma de Barcelona, ES-08193 Bellaterra (Barcelona), Spain — [5]ICREA, ES-08010 Barcelona, Spain

Understanding the resource consumption in distributed scenarios is one of the main goals of quantum information theory. A prominent example for such a scenario is the task of quantum state merging where two parties aim to merge their parts of a tripartite quantum state. In standard quantum state merging, entanglement is considered as an expensive resource, while local quantum operations can be performed at no additional cost. Here, we consider the task of incoherent quantum state merging, where one of the parties has free access to local incoherent operations only. In this case the resources of the process are quantified by pairs of entanglement and coherence. We develop tools for studying this process, and apply them to several relevant scenarios. While quantum state merging can lead to a gain of entanglement, our results imply that no merging procedure can gain entanglement and coherence at the same time. We also provide a general lower bound on the entanglement-coherence sum, and show that the bound is tight for all pure states.
For more details see Phys. Rev. Lett. **116**, 240405 (2016).

Q 32.5 Wed 15:30 P 2

Quantum fidelity of symmetric multipartite states — •Antoine Neven[1], Pierre Mathonet[2], Otfried Gühne[3], and Thierry Bastin[1] — [1]CESAM Research Unit, Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, 4000 Liège, Belgium — [2]Département de Mathématique, Université de Liège, 4000 Liège, Belgium — [3]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, D-57068 Siegen, Germany

For two symmetric quantum states one may be interested in maximizing the overlap under local operations applied to one of them. The question arises whether the maximal overlap can be obtained by applying the same local operation to each party. We show [1] that for two symmetric multiqubit states and local unitary transformations this is the case; the maximal overlap can be reached by applying the same unitary matrix everywhere. For local invertible operations (stochastic local operations assisted by classical communication equivalence), however, we present counterexamples, demonstrating that considering the same operation everywhere is not enough.

[1] A. Neven, P. Mathonet, O. Gühne, and T. Bastin, Phys. Rev. A **94**, 052332 (2016).

Q 32.6 Wed 15:45 P 2

Absolutely maximally entangled states of seven qubits do not exist — •Felix Huber[1], Otfried Gühne[1], and Jens Siewert[2,3] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany — [2]Departamento de Química Física, Universidad del País Vasco UPV/EHU, E-48080 Bilbao, Spain — [3]IKERBASQUE Basque Foundation for Science, E-48013 Bilbao, Spain

Pure multiparticle quantum states are called absolutely maximally entangled if all reduced states obtained by tracing out at least half of the particles are maximally mixed. We provide a method to characterize these states for a general multiparticle system. With that, we prove that a seven-qubit state whose three-body marginals are all maximally mixed does not exist. Furthermore, we obtain an upper limit on the possible number of maximally mixed three-body marginals and identify the state saturating the bound. This solves the seven-particle problem as the last open case concerning maximally entangled states of qubits.

Q 32.7 Wed 16:00 P 2

Almost all pure four-qubit states are uniquely determined by their two-body marginals — •Nikolai Wyderka, Felix Huber, and Otfried Gühne — Naturwissenschaftlich Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany

Thermal states of Hamiltonians with two-body interactions are of great interest in quantum information processing as these states may be experimentally realised by engineering the Hamiltonian. The question of whether the ground state of such an Hamiltonian is unique is closely connected to the question whether the state is uniquely determined by its two-body marginals. For generic three-qubit states, it was shown that generic pure states are uniquely determined among all states by their two-body marginals [1]. We show that generic four-qubit states are uniquely determined among pure states by their two-body marginals.

[1] N. Linden, S. Popescu, and W. K. Wootters. Phys. Rev. Lett. 89, 207901 (2002).

Q 33: Quantum Information: Solid State Systems II

Time: Wednesday 14:30–16:15 Location: P 3

Q 33.1 Wed 14:30 P 3

Quantum photonics with superconducting single-photon detectors on silicon chips — •Carsten Schuck[1,2], Xiang Guo[1], Linran Fan[1], Hojoong Jung[1], Xiaosong Ma[1], Menno Poot[1], Chang-Ling Zou[1], and Hong Tang[1] — [1]Department of Electrical Engineering, Yale University, New Haven, CT 06511, USA — [2]Physikalisches Institut, Westfälische Wilhelms-Universität Münster, Germany

Single photons in nanophotonic circuits on silicon chips hold great promise for scalable quantum information processing. Sources of nonclassical light, integrated optical circuit components and waveguide-coupled single-photon detectors are essential ingredients of a photonic quantum processor. Here we report progress on realizing these components with standard semiconductor thin-film technology on silicon chips. We demonstrate quantum interference of photons from spontaneous parametric down conversion on an integrated directional coupler fabricated from nanophotonic silicon nitride waveguides. We observe two-photon interference with 97% visibility when measuring photon statistics with waveguide-coupled superconducting nanowire single-photon detectors directly on-chip [1]. Further we realize a spontaneous parametric down conversion source in micro-ring resonators made from aluminum nitride. Antibunching of heralded single-photons with high modal purity [2] highlights the suitability of this source for quantum information processing.

[1] Schuck te al., Nature Comm. 7, 10352 (2016).
[2] Guo te al., Light: Science & Applications 6, e16249 (2017).

Q 33.2 Wed 14:45 P 3

Optical quantum memories with colour centre ensembles in diamond — •Jonas Nils Becker[1], Christian Weinzetl[2], Johannes Görlitz[1], Eilon Poem[3], Joshua Nunn[2], Ian Alexander Walmsley[2], and Christoph Becher[1] — [1]Fakultät NT (Fachrichtung Physik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken, Germany — [2]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom — [3]Weizmann Institute of Science, Rehovot 7610001, Israel

The reliable storage of a quantum state in the form of a photon without destroying its coherence properties remains a significant challenge in the field of quantum information processing. One scheme to realize such an optical quantum memory is a Raman-based storage in a dense ensemble of emitters via an off-resonant two-photon absorption of single photons, aided by a strong auxiliary control-field in a Λ-type configuration. In this scheme, the memory bandwidth is only limited by the ground state splitting of the ensemble. We here propose the use of an ensemble of silicon vacancy (SiV) colour centres in diamond as a storage medium to realize such a memory. A large ground state splitting of 48 GHz allows for storing picosecond photons over tens of nanoseconds enabling applications in e.g. deterministic single photon sources or buffer memories. We here present theoretical as well as first experimental results demonstrating the feasibility of an SiV-based memory as well as storage-time-extension using Hahn-Echo pulse sequences in inhomogeneously broadened ensembles.

Q 33.3 Wed 15:00 P 3

Optical coherence in 1.53 um Erbium transition in ^{7}LiYF$_4$ crystal below 1K — •Nadezhda Kukharchyk[1], Dmitriy Sholokhov[1], Stella L. Korableva[2], Alexey A. Kalachev[3], and Pavel Bushev[1] — [1]Experimentalphysik, Universität des saarlandes, D-66123 Saarbrücken, Germany — [2]Kazan Federal University, 420008 Kazan, Russian Federation — [3]Kazan Institute of Physics and Tech-

nology, 420029 Kazan, Russian Federation

Rare earth doped materials find nowadays many applications in various industrial and research fields. When put into wide band gap crystals, rare earths exhibit long optical and microwave coherence times, which is in a great interest for quantum information processing. In current work, we have studied Erbium monoisotopic $LiYF_4$ crystals. Such isotopically pure crystals have very low optical inhomogeneous broadening of approx. 10 MHz; This opens many possibilities to implement these crystals as off-resonant Raman quantum memory or as frequency converter. Here, we demonstrate dependencies of coherence times of ^{166}Er in $^{7}LiYF_4$ on magnetic field and on temperature. Several crucial effects were observed: "frozen core" and ZEFOZ, which allowed to reach optical coherence times up to 75 us at magnetic field of 200 mT.

Q 33.4 Wed 15:15 P 3

Arbitrary n-Qubit State Transfer Using Coherent Control and Simplest Switchable Local Noise — Ville Bergholm[1], •Frank K. Wilhelm[2], and Thomas Schulte-Herbrüggen[1] — [1]Dept. Chemistry, Technical University of Munich (TUM), D-85747 Garching, Germany — [2]Institute for Theoretical Physics, University of Saarland, 66123 Saarbrücken, Germany

We study the reachable sets of open n-qubit quantum systems, the coherent parts of which are under full unitary control, with time-modulable Markovian noise acting on a single qubit as an additional degree of incoherent control. In particular, adding bang-bang control of amplitude damping noise (non-unital) allows the dynamic system to act transitively on the entire set of density operators. This means one can transform any initial quantum state into any desired target state. Adding switchable bit-flip noise (unital), on the other hand, suffices to explore all states majorised by the initial state. We have extended our open-loop optimal control package dynamo to also handle incoherent control so that these unprecedented reachable sets can systematically be exploited in experiments. We propose implementation by a GMon, a superconducting device with fast tunable coupling to an open transmission line, and illustrate how open-loop control with noise switching can accomplish all state transfers without the need for measurement-based closed-loop feedback schemes with a resettable ancilla.

Q 33.5 Wed 15:30 P 3

High-fidelity qbuit State Tomographie in the Nonlinear Dispersive Regime — •Marius Schöndorf[1], Luke C. G. Govia[1,2], and Frank K. Wilhelm-Mauch[1] — [1]Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany — [2]Departement of Physics, McGill University, Montreal, Quebec, Canada H3A 2T8

Superconducting qubits are promising candidate for the realization of a scalable quantum computer. An important step for real implementations is qubit state tomography. In the past we presented a scheme to readout sinlge qubit states as well as multiple parities with a microwave photon counter. Especially parity readout plays an important role for the implementation of error correction codes. Since most of the existing microwave photon counters do not have very high efficiencies, such that it is necessary to increase contrast in the readout cavity.

In this work we theoretically describe multiple qubits dispersively coupled to a driven cavity. We are especially interested in the regime where the linear dispersive approximation breaks down, which means the photon number in the cavity exceeds a specific number $n > n_{\text{crit}}$. To get a valid theoretical description of that system we need to use the exact dispersive transformation, which is also valid for high cavity occupation. The result is a nonlinear behavior for high drive strengths which has a strong dependence on the state of the N qubits coupled to the cavity which leads to a very high contrast of about 10^5 photons in the cavity. We show that this can be used to perform various multi qubit measurements with very high fidelity.

Q 33.6 Wed 15:45 P 3

Robust quantum optimizer with full connectivity — Simon Nigg, •Niels Lörch, and Rakesh Tiwari — Departement Physik, Universität Basel, Schweiz

Quantum phenomena have the potential to speed up the solution of hard optimization problems. For example quantum annealing, based on the quantum tunneling effect, has recently been shown to scale exponentially better with system size as compared with classical simulated annealing. However, current realizations of quantum annealers with superconducting qubits face two major challenges. First, the connectivity between the qubits is limited, excluding many optimization problems from a direct implementation. Second, decoherence degrades the success probability of the optimization. We address both of these shortcomings and propose an architecture in which the qubits are robustly encoded in continuous variable degrees of freedom. Remarkably, by leveraging the phenomenon of flux quantization, all-to-all connectivity is obtained without overhead. Furthermore, we demonstrate the robustness of this architecture by simulating the optimal solution of a small instance of the NP-hard and fully connected number partitioning problem in the presence of dissipation.

Reference: arXiv:1609.06282

Q 33.7 Wed 16:00 P 3

Non-Markovianity in driven open quantum systems — •Rebecca Schmidt[1,2,3], Tapio Ala-Nissilä[3,4], and Sabrina Maniscalco[1,2] — [1]Turku Centre for Quantum Physics, Department of Physics and Astronomy, University of Turku, FIN-20014 Turku, Finland — [2]Center for Quantum Engineering, Department of Applied Physics,Aalto University School of Science, P.O. Box 11000, FIN-00076 Aalto, Finland — [3]COMP Center of Excellence, Department of Applied Physics, Aalto University, P.O. Box 11000, FI-00076 Aalto, Finland — [4]Department of Physics, P.O. Box 1843, Brown University, Providence, Rhode Island 02912-1843, U.S.A.

Open system dynamics inevitably experience losses in particular in strongly coupled systems such as condensed matter devices. However, it has be shown that non-Markovian dynamics give rise to information backflow. Here we show, how driving changes this information backflow as well as if and how tailored driving can use information backflow as a resource.

Q 34: Quantum Effects: Entanglement and Decoherence

Time: Wednesday 14:30–16:45 Location: P 4

Group Report Q 34.1 Wed 14:30 P 4

Tunable entanglement resource in elastic electron-exchange collisions out of chaotic spin systems — •Bernd Lohmann[1], Karl Blum[1], and Burkhard Langer[2] — [1]Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Strasse 9, 48149 Münster, Germany — [2]Physikalische Chemie, Freie Universität Berlin, Taku-Strasse 3, 14195 Berlin, Germany

Elastic collisions between initially unpolarized electrons and hydrogen-like atoms are discussed aiming to analyze the entanglement properties of the correlated final spin system. Explicit spin-dependent interactions are neglected and electron exchange only is taken into account. It is shown that the final spin system is completely characterized by a single spin correlation parameter depending on scattering angle and energy. Its numerical value identifies the final spins of the collision partners to be either in the separable, entangled, or Bell correlated regions.

The symmetry of the scattering process allows for the construction of explicit examples applying methods of classical communication and local operations for illustrating the concepts of nonlocality versus separability.

It is shown that strong correlations can be produced violating Bell's inequalities significantly. Furthermore, the degree of entanglement can be continuously varied simply by changing either the scattering angle and/or energy. This allows for the generation of tunable spin pairs with any desired degree of entanglement. We suggest to use such nonlocally entangled spin pairs as a resource for further experiments, for example in quantum information processes.

Q 34.2 Wed 15:00 P 4

Observation of genuine three-photon interference — •Thomas Kauten[1], Sascha Agne[2], Jeongwan Jin[2], Evan Meyer-Scott[2,3], Jeff Salvail[2], Deny Hamel[4], Kevin Resch[2], Gregor Weihs[1], and Thomas Jennewein[2] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada — [3]Department of Physics, University of Paderborn, 33098 Paderborn, Germany — [4]Département de Physique et d'Astronomie, Université de Moncton, Moncton, New Brunswick E1A 3E9, Canada

Multiparticle quantum interference is important for our understanding and exploitation of quantum information and for fundamental tests of quantum mechanics [1]. An example for multi-partite correlations is the Greenberger-Horne-Zeilinger (GHZ) state [2]. In a GHZ-state, three particles are correlated while no pairwise correlation is found. Those strong correlations have been studied theoretically since 1990 but no three-photon GHZ interferometer has been realized experimentally. Here we demonstrate three-photon interference that does not originate from two-photon or single photon interference. We observe phase-dependent variation of three-photon coincidences with $(90.5 \pm 5.0)\%$ visibility [3] in a generalized Franson interferometer [4] using energy-time entangled photon triplets [5].

[1] Pan et al., Rev. Mod. Phys. 84, 777 (2012). [2] Greenberger et al., Am. J. Phys. 58, 1131 (1990). [3] Agne et al., arXiv:1609.07508 (2016). [4] Franson Phys. Rev. Lett. 62, 2205 (1989). [5] Hübel et al., Nature 466, 601-603 (2010).

Q 34.3 Wed 15:15 P 4

Autonomous quantum error correction with application to quantum metrology — •Florentin Reiter[1,2,4], Anders S. Sørensen[3], Peter Zoller[1,2], and Christine A. Muschik[1,2] — [1]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria — [2]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [3]Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark — [4]Current address: Harvard University, Department of Physics, 17 Oxford Street, Cambridge, MA 02138, USA

We present a quantum error correction scheme that stabilizes a qubit by coupling it to an engineered environment which protects it against spin- or phase flips. Our scheme uses always-on couplings that run continuously in time and operates in a fully autonomous fashion without the need to perform measurements or feedback operations on the system. The correction of errors takes place entirely at the microscopic level through a build-in feedback mechanism. Our dissipative error correction scheme can be implemented in a system of trapped ions and can be used for improving high precision sensing. We show that the enhanced coherence time that results from the coupling to the engineered environment translates into a significantly enhanced precision for measuring weak fields. In a broader context, this work constitutes a stepping stone towards the paradigm of self-correcting quantum information processing.

Q 34.4 Wed 15:30 P 4

Subradiant Emission from Statistically Independent Classical Light Sources — •Daniel Bhatti[1,2], Raimund Schneider[1,2], Thomas Mehringer[1,2], Steffen Oppel[1], 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

Super- and subradiance, i.e., the cooperative emission of spontaneous radiation by an ensemble of identical two-level atoms, is one of the intriguing problems in quantum optics. While superradiance is usually observed from symmetric Dicke-states, subradiance is typically attributed to nonsymmetric Dicke-states [1]. Recent theoretical and experimental investigations of higher-order intensity correlations have shown that even thermal light sources (TLS) are able to emit superradiant light in particular directions [2,3]. Here, we investigate the Nth-order intensity correlation functions of N TLS for different detector configurations leading to the production of directional subradiance. By relating the phenomenon to subradiance of antisymmetric quantum states, we find that the classical directional subradiance reflects a quantum feature. We present the first measurements of directional subradiant emission from TLS confirming the theoretical predictions.

[1] R. H. Dicke, Phys. Rev. 93, 99 (1954).
[2] S. Oppel, et al., Phys. Rev. Lett. 113, 263606 (2014).
[3] D. Bhatti, et al., Phys. Rev. A 94, 013810 (2016).

Q 34.5 Wed 15:45 P 4

Stability of quantum statistical ensembles with respect to local measurements — •Walter Hahn[1,2] and Boris V. Fine[1,2] — [1]Skolkovo Institute of Science and Technology, Moscow (Russia) — [2]Institute for Theoretical Physics, University of Heidelberg (Germany)

We introduce a stability criterion for quantum statistical ensembles describing macroscopic systems. An ensemble is called *stable* when a small number of local measurements cannot significantly modify the probability distribution of the total energy of the system. In this talk, we apply this criterion to lattices of spins-1/2 and particularly focus on recent results obtained in numerical simulations of interacting spin systems. Thereby we show that the canonical ensemble is nearly stable, whereas statistical ensembles with much broader energy distributions are not stable. In the context of the foundations of quantum statistical physics, this result justifies the use of statistical ensembles with narrow energy distributions such as canonical or microcanonical ensembles.

Q 34.6 Wed 16:00 P 4

Two Oscillators and Spectral Entanglement — •Andreas Kurcz and Carsten Henkel — Institute of Physics and Astronomy, University of Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam, Germany

We consider two coupled oscillators within independent heat baths as a toy-model to study heat transport [1] and non-equilibrium steady states [2] in open quantum systems. We analyse correlation functions of the oscillator coordinates that provide a spectral representation of the covariance matrix familiar from continuous variables [3]. The Fluctuation Dissipation Theorem [4] is applied in order to generalize criteria for entanglement into the frequency domain. One key concept is the linear response matrix whose peaks allow to identfy the normal modes of the coupled system. We explore a wavelet analysis of quadratures to provide a link between entanglement witnesses and experimental protocolls. The model is very genereal and may cover different regimes dependent on the spectral densities of the heat baths, temperatures, and coupling strength.

[1] G. Barton, J. Phys.: Condens. Matter 27, 214005 (2015). [2] I. Dorofeyev, Can. J. Phys. 91, 537 (2013). [3] C. Weedbrook et. al., Rev. Mod. Phys. 84, 621 (2012). [4] G. W. Ford, J. T. Lewis, and R. F. O' Connel, Phys. Rev. A 37, 4419 (1988).

Q 34.7 Wed 16:15 P 4

Experimental observation of non-Markovianity in a trapped-ion quantum system — •Matthias Wittemer, Govinda Clos, Ulrich Warring, Heinz-Peter Breuer, and Tobias Schaetz — Physikalisches Institut, 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 a high level of 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 experimentally study the flow of information in a closed quantum system between a subsystem and its environment and characterize associated memory effects [2]. We prepare different environmental states and realize different interactions between system and environment to measure the non-Markovianity as a function of these parameters.

[1] G. Clos *et al.*, Phys. Rev. Lett. **117**, 170401 (2016)
[2] H.-P. Breuer *et al.*, Phys. Rev. Lett. **103**, 210401 (2009)

Q 34.8 Wed 16:30 P 4

Extensions of a quantum transport model of the FMO photosynthetic complex — •Hlér Kristjánsson[1,2], Jonathan Brugger[1], Gabriel Dufour[1], Christian Scheppach[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Alberts-Ludwigs-Universität, Freiburg i. Br., Germany — [2]Blackett Laboratory, Imperial College, London, United Kingdom

The potential role of non-trivial quantum coherence effects in the Fenna-Matthews-Olson (FMO) photosynthetic complex has been the subject of various experiments as well as theoretical quantum transport models since the discovery of remarkably long-lived coherences in the complex ten years ago. The FMO complex connects the photon-capturing antenna to the reaction centre in green sulphur bacteria by acting as a wire for energy transport. It can be modelled as a disordered system with a few sites, each described by a two-level system.

In this talk we consider the model for quantum transport in disordered systems proposed by Walschaers *et al.* [1], based on centrosymmetry of the Hamiltonian and a dominant doublet coupling between the input and output sites. We then discuss three extensions to this model to create a more realistic description of energy transport in the FMO complex: (i) variable energy levels for different sites, (ii) coupling to vibrational modes of the system, and (iii) including the coupling of the wire to both the antenna and the reaction centre.

[1] M. Walschaers, R. Mulet, T. Wellens, and A. Buchleitner, *Phys. Rev. E* **91**, 042137 (2015)

Q 35: Laser Development and Applications (Spectroscopy)

Time: Wednesday 14:30–16:30 Location: P 5

Q 35.1 Wed 14:30 P 5

A pulsed single-mode Ti:sapphire laser for high-resolution resonance ionization spectroscopy — •Dominik Studer[1], Tobias Kron[1], Sebastian Raeder[2], Volker Sonnenschein[3], Pascal Naubereit[1], and Klaus Wendt[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz — [2]GSI Darmstadt — [3]Department of Quantum Engineering, Nagoya University

Resonance ionization spectroscopy (RIS) is a well-established technique for both atomic and nuclear research. Through the stepwise excitation and ionization of an atom individual transitions can be probed, allowing the extraction of fundamental parameters, such as isotope shifts and nuclear moments, provided an adequately narrow experimental linewidth is realized. Due to their high reliability and stability, pulsed Ti:sapphire lasers as designed at JGU Mainz are used at on-line laser ion sources worldwide. The standard design features a Z-shaped standing wave cavity, pumped by a frequency-doubled Nd:YAG laser with a repetition rate of 10 kHz. The output power reaches up to 4 W with pulse lengths of 40 ns. Frequency selection is achieved by a combination of a Lyot-Filter and a thin Etalon, resulting in a spectral linewidth of ≈5 GHz. Operation on a single longitudinal mode can be achieved using a ring cavity design featuring an additional air-spaced etalon, resulting in ≈50 MHz linewidth. Compared to the previously used technique of injection-locking, this design implies an unseeded single-mode operation, greatly reducing the complexity of the system. Moreover the wavelength range is not constrained by a master laser, allowing easy set-up and scanning operation.

Q 35.2 Wed 14:45 P 5

Quantum metamaterials as an active lasing medium: Effects of disorder — •Martin Koppenhöfer[1,2], Michael Marthaler[2], and Gerd Schön[2] — [1]University of Basel, Basel, Switzerland — [2]Karlsruhe Institute of Technology, Karlsruhe, Germany

A metamaterial formed by artificial atoms, e.g., superconducting circuits or quantum dots, can serve as an active lasing medium when coupled to a microwave resonator. For these artificial atoms, in contrast to real atoms, variations in their parameters cannot be avoided. We examine the influence of disorder on such a multiatom lasing setup. We find that the lasing process evolves into a self-organized stationary state that is quite robust against disorder. The reason is that photons created by those atoms which are in or close to resonance with the resonator stimulate the emission also of more detuned atoms. Not only the number of photons grows with the number of atoms but also the width of the resonance as a function of the detuning. Similar properties are found for other types of disorder such as variations in the individual coupling. We present relations on how the allowed disorder scales with the number of atoms and confirm it by a numerical analysis. We also provide estimates for the sample-to-sample variations to be expected for setups with moderate numbers of atoms.

Q 35.3 Wed 15:00 P 5

Laser System Technology for Quantum Optics Experiments in Space — •Kai Lampmann[1], Moritz Mihm[1], André Wenzlawski[1], Ortwin Hellmig[6], 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]FBH, Berlin — [4]IQO, LU Hannover — [5]ZARM, Bremen — [6]ILP, UHH Hamburg

Numerous applications of quantum optics demand for operating experiments in extreme environments. Leaving the lab poses strict requirements to the experimental systems, especially the laser systems, in terms of miniaturization, power consumption, and mechanical and thermal stability. We follow a hybrid approach to build laser systems that can overcome these issues.

Optical bench systems using a set of specially designed freespace optics based on glass ceramics are combined with fiberintegrated components like splitters, modulators or resonators. Our systems fulfill all different functions such as laser frequency stabilization, switching and distribution of laser light.

Successful sounding rocket missions show that our systems can overcome the extreme loads of a rocket launch and that we are able to bring laser systems into space.

Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under grant numbers 50 WP 1433 and 50 WM 1345, 1646.

Q 35.4 Wed 15:15 P 5

Dy^{3+}:Lu_2O_3 as a promising gain material for mid-infrared lasers — •Alexander M. Heuer[1,2], Patrick von Brunn[1,2], and Christian Kränkel[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging

The cubic sesquioxide Lu_2O_3 is a suitable host material for mid-infrared laser applications due to its high thermal conductivity and low phonon energy. We report on the first growth from the melt and spectroscopic analysis of monocrystalline Dy^{3+}:Lu_2O_3 in the mid-infrared spectral range. Absorption and emission cross-sections in the wavelength range between 2 μm and 3.8 μm were determined. Gain cross-sections in the same wavelength region were derived and point towards possible laser action at 3256 nm and 3388 nm. The most suitable pump wavelengths for in-band pumping directly into the emitting multiplet were found to be 2713 nm and 2776 nm. This allows for pumping by an erbium-based mid-infrared laser. From the emission cross-sections the lifetime of the emitting $^6H_{13/2}$ multiplet has been calculated to be in the order of 20 ms. Corresponding measurements are in progress. Compared to the values reported for the mid-infrared laser material Dy:ZBLAN the cross-sections of Dy^{3+} in Lu_2O_3 are about 50 % higher. This reveals that Dy^{3+}:Lu_2O_3 is a promising candidate for the first mid-infrared oxide host material based on the Dy^{3+}-ion.

Q 35.5 Wed 15:30 P 5

Low drift cw-seeded high-repetition-rate optical parametric amplifier for fingerprint coherent Raman spectroscopy — •Joachim Krauth[1], Tobias Steinle[1], Bowen Liu[2], Moritz Floess[1], Heiko Linnenbank[1], Andy Steinmann[1], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart — [2]Ultrafast Laser Laboratory, Tianjin University

We introduce a broadly tunable robust source for fingerprint (170 - 1620 cm^{-1}) Raman spectroscopy. A cw thulium-doped fiber laser, gap-free tunable from 1770 - 2030 nm, seeds an OPA, which is pumped by a 7-W, 450-fs Yb:KGW bulk mode-locked oscillator with 41 MHz repetition rate. The OPA is designed in double-pass configuration for power scaling and delivers a signal output power of around 1 W over most of the tuning range. The output radiation of the OPA signal is frequency doubled in a PPLN crystal and generates 0.7 - 1.3-ps-long narrowband pump pulses for the subsequent Raman spectroscopy that are tunable between 885 and 1015 nm with >80 mW average power. The Stokes beam is delivered by a part of the oscillator output, which is sent through an etalon to create pulses with 1.7 ps duration. We demonstrate a stimulated Raman gain measurement of toluene in the fingerprint spectral range. Here we use an acousto-optic modulator to modulate the pump pulse, while the Stokes intensity is detected using a single silicon photodiode, which is connected to a high-frequency lock-in amplifier. Our system combines the simplicity and the robustness of an OPA with the ultra-low intensity noise of a solid-state oscillator. Furthermore, the cw seeding intrinsically ensures low spectral drift.

Q 35.6 Wed 15:45 P 5

Spatial Nonuniformity and Photochemical Doping in exfoliated WS2 Monolayers — •Ioannis Paradisanos — N. Plastira 100, Heraklion, Crete, Greece

Monolayers of transition metal dichalcogenides (TMDs) are promising new materials for future 2D nanoelectronic systems. With their tunable direct gap in the visible range of the optical spectrum and high surface-to-volume ratio, these 2D semiconducting systems are ideal for field-effect transistors, photovoltaics, light-emitting diodes, single-atom storage, molecule sensing and quantum-state metamaterials.

Here we report on the extraordinary photoluminescence (PL) and Raman properties, not only of the physical but also of intentionally created via femtosecond laser ablation, boundaries of mechanically exfoliated WS2 monolayers. In particular, it is shown that the edges of such monolayers exhibit significant Raman shifts as well as remarkably increased PL efficiency compared to their respective central area with the emission channels being of different origin. Moreover, by exploiting the interaction of UV nanosecond pulses with WS2 monolayers in rich Cl2 environment, a fine control of the crystal*s carrier density can be achieved. This is confirmed by micro-PL measurements at 78K that show significant energy shifts of the neutral and charged exciton*s emission. At the same time, micro-Raman experiments reveal systematic shifts of the -doping sensitive- A1* vibrational mode.

We envisage that these novel findings could find diverse applications in the development of TMDs-based optoelectronic devices.

Q 35.7 Wed 16:00 P 5

Mid-IR laser-based FTIR imaging using a broadband fs laser source at 73 MHz repetition rate — •Florian Mörz, Rostyslav Semenyshyn, Tobias Steinle, Frank Neubrech, Andy Steinmann, and Harald Giessen — 4th Physics Institute and Research Center SCOPE, University of Stuttgart, 70550 Stuttgart,Germany

We demonstrate FTIR imaging of sub-wavelength layers of C60 and Pentacene at 7 μm using a broadband laser source. Imaging has been conducted by using aperture sizes as small as 10 x 10 μm with a 36x microscope objective. A 100 x 100 μm image of the molecule layers has been measured. A signal-to-noise ratio that exceeds common FTIR light sources, such as globars or synchrotrons, due to a several orders of magnitude higher brilliance has been observed. The applied laser source is based on the ffOPO system presented in [1, 2]. Here, a commercially available Yb:CALGO laser, providing 98 fs pulses at 73 MHz repetition rate, is used as a pump oscillator. The post-amplified ffOPO system converts the pump light to the 1.4 - 4 μm wavelength range. By difference frequency generation between signal and idler in $AgGaSe_2$ up to 1 mW average power at 7 μm with 446 nm (93 cm^{-1}) bandwidth ($1/e^2$) is generated. The system exhibits superior long term stability over several hours. In conclusion, this laser based FTIR setup enables applications such as single nano-antenna measurements or protein sensing based on surface-enhanced infrared absorption (SEIRA).

[1] F. Moerz et al., Opt. Exp. **23**, 23960 (2015)
[2] T. Steinle et al., Opt. Lett. **41**, 4863 (2016)

Q 35.8 Wed 16:15 P 5

Towards Precision Infrared Spectroscopy on Small Molecules — •Arthur Fast[1], John E. Furneaux[2], and Samuel A. Meek[1] — [1]Max Planck Institute for Biophysical Chemistry, Germany — [2]University of Oklahoma, USA

Our goal is a high resolution measurement of the two-photon $v = 2 \leftarrow v = 0$ vibrational transitions in the hydroxyl (OH) radical with a relative accuracy of 10^{-14}. These transitions can be used for a test of a possible time variation of the electron-proton mass ratio. The core of this endeavor is a laser beam in the mid infrared region at 2.9 μm with a narrow optical linewidth below 1 kHz. This is the idler wavelength of an optical parametric oscillator (OPO) pumped at 1064 nm by a Nd:YAG laser. The same laser is also frequency-doubled and locked to a molecular iodine transition at 532 nm. By doing this, the Nd:YAG laser obtains a high short term stability, around 10^{-14} at the one-second timescale. To transfer this stability to the idler wavelength of the OPO at 2.9 μm we make use of an optical frequency comb. The frequency comb is stabilized to the Nd:YAG laser, and the OPO is stabilized to the frequency comb by controlling its cavity length with a piezo mirror. The frequency comb is also used to compare the measured absolute frequencies of the various lasers to a GPS-linked radio frequency reference. In this way, we obtain a long-term stability and absolute accuracy for our spectroscopic measurements.

Q 36: Photonics I

Time: Wednesday 14:30–16:45 Location: P 11

Group Report Q 36.1 Wed 14:30 P 11

Light Localisation Schemes in Microstructured Optical Fibres — •Stavros Pissadakis — FORTH-IESL, Heraklion, Greece

Microstructured optical fibres (MOFs) and photonic crystal fibres (PCFs) are considered high versatility photonic platforms for the development of multi-functional and high-performance optical devices for optical communication, sensing and imaging applications. Light localisation examples in those fibres types will be presented, while referring to the implementation into those fibres of whispering gallery mode (WGM) resonances, photonic band gap tailoring, and multicore guidance, while targeting sensing, material studies, and slow light applications.

Q 36.2 Wed 15:00 P 11

Whispering Gallery Mode microbarrel resonators fabricated by multiphoton polymerization technique onto tapered standard telecom fibers — Vasileia Melissinaki[1,2], Maria Farsari[1], and •Stavros Pissadakis[1] — [1]Foundation for Research and Technology-Hellas (FORTH), Institute of Electronic Structure and Laser (IESL), 71110 Heraklion, Greece — [2]Department of Physics, University of Crete, Heraklion, Greece

Whispering Gallery Mode (WGM) microbarrel resonators fabricated by multiphoton polymerization technique onto tapered standard telecom fibers are demonstrated. The material used for the fabrication of the microstructure is a zirconium-silicon, organic-inorganic hybrid photosensitive material. Spectra recorded in transmission mode correlate to the diameter of the microbarrels, as well as their thickness and the fabrication position onto the tapered fiber. Moreover, considering the symmetry of these microbarrel resonators, polarization spectra were also studied. Finally, these WGM microbarrel resonators are used as sensing probes for tracing the vapors of common organic solvents.

Q 36.3 Wed 15:15 P 11

Efficient extraction of photons from a single defect in hBN using a nanofiber — •Andreas W. Schell[1], Hideaki Takashima[1], Toan Trong Tran[2], Igor Aharonovich[2], and Shigeki Takeuchi[1] — [1]Kyoto University, Kyoto, Japan — [2]University of Technology, Sydney, Australia

Efficient extraction of photons from quantum emitters is an important prerequisite for the use of such emitters in quantum optical applications as single photons sources or sensors. One way to achieve this is by coupling to a suited photonics structure, which guides away the emitter light. Here, we show the coupling of a single defect in hexagonal boron nitride (hBN) to a tapered optical fiber via a nanomanipulation technique. Defects in hBN are capable of emitting single photons at room temperature while being photostable at the same time two properties that make them ideal candidates for integration in single photon sources. The high control the manipulation technique provides avoids covering the whole nanofiber with emitters. We characterize the coupled system in terms of achievable count rates, saturation intensity, and spectral properties. Antibunching measurements are used to proof the single emitter nature of the defect. Our results pave the way for integration of single defects in hBN into photonic structure and their use as single photon sources in quantum optical applications.

Q 36.4 Wed 15:30 P 11

Nanofiber Bragg grating cavities — •Andreas W. Schell, Hideaki Takashima, Atsushi Fukuda, Hironaga Maruya, and Shigeki Takeuchi — Kyoto University, Kyoto, Japan

Coupling the light emitted from quantum emitters like atoms, molecules, or defect centers into the guided mode of a single mode optical fiber is highly important for scaling up quantum optics experiments, since it provides the possibility to interconnect experiments at different locations and ensures high mode overlap of photons from different sources. Here, we present a photonic nanocavity on a tapered optical fiber. The cavities are formed by two Bragg mirrors fabricated by an ion beam [1]. Characterization in terms of transmission, reflection, and polarization are performed and compared with numerical simulations [2]. The quality factors of the fabricated devices can reach values over 300 while the mode volume is smaller than the cubic wavelength. Simulations indicate that a Purcell enhancement of 19.1 with 82 % coupling efficiency can be reached using this cavities. A comparison of cavities fabricated using a gallium beam is compared with cavities made using a helium beam giving insights about implantation of gallium in the ion beam milling fabrication of resonators. Using the knowledge from experiment and simulation, new designs for nanofiber Bragg grating cavities are developed and tested. [1] A W Schell et al. Sci. Rep. 5, 9619 (2015) [2] H Takashima et al. Opt. Express 24, 15050-15058 (2016)

Q 36.5 Wed 15:45 P 11

The Akhmediev Breather in the presence of loss — •Alexander Hause, Christoph Mahnke, and Fedor Mitschke — Universität Rostock, Institut für Physik, Albert-Einstein-Str. 23, 18059 Rostock

Light propagation in optical fibers is described by the nonlinear Schrödinger equation. A type of solution known as Akhmediev Breather receives much attention recently. It describes a cw background wave on top of which a perturbation waxes and wanes; at its culmination point it forms a periodic sequence of pulses. In realistic situations, the growth-and-decay undergoes periodic recurrence; this has been described in terms of the Fermi-Pasta-Ulam phenomenon [1].

If for realism we introduce (localized) loss (or gain) we find an expression for the recurrence period, and a peculiar behavior: The recurrence pattern phase-shifts by π if there is loss; for gain it remains unshifted. Recently researchers have discovered a similar phase shift in corresponding experiments in a lossy wave tank [2]. However, the Nonlinear Schrödinger equation is integrable and does not describe a lossy channel. We are looking for a comprehensive description of these phenomena. Surely, such description must, in the low-power limit, reproduce the Temporal Talbot effect [3] which has the same phase reversal.

[1] S. A. Chin et al., Phys. Rev. E **92**, 063202 (2015)
[2] O. Kimmoun et al., ArXiv 1602.01604v1 (2016)
[3] U. Morgner, FM, Optics & Photonics News **9**, 45 (1998)

Q 36.6 Wed 16:00 P 11

Solitons and loss: a new take at nonintegrability — •Christoph Mahnke, Alexander Hause, and Fedor Mitschke — Universität Rostock, Institut für Physik, Albert-Einstein-Str. 23, 18059 Rostock

Fiber-optic soliton pulses are described by the Nonlinear Schrödinger equation which is integrable. Integrability is an idealization, rendered invalid even by a minimal amount of loss (or gain). Attempts to assess the fate of the soliton in the lossy case have been restricted to perturbation analysis where it is assumed that the loss is very small. We present a new approach which is physically intuitive but does not make this last assumption. It can quantify the reshaping of the soliton, as well as the generation of linear radiation, for both localized and distributed loss. The perturbative limit is recovered as a special case. Outside this limit, we can quantitatively describe how the soliton eventually decays when it continuously loses energy. The approach can also be applied to the case of gain.

Q 36.7 Wed 16:15 P 11

Bloch oscillations sustained by nonlinearity — •Rodislav Driben[1], Vladimir Konotop[2], Torsten Meier[1], and Alexey Yulin[3] — [1]Department of Physics and CeOPP, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany — [2]Centro de Fisica Teorica e Computacional and Departamento de Fisica, Universida de Lisboa — [3]ITMO University, 49 Kronverskii Ave., St. Petersburg 197101, Russian Federation

We demonstrate that, contrary to general belief, a nonlinearity may play a constructive role in supporting Bloch oscillations in a model which is discrete, in one dimension and continuous in the orthogonal one. Such a model can be experimentally realized in several fields of physics such as optics and Bose-Einstein condensates. We demonstrate that designing an optimal relation between the nonlinearity and the linear gradient strength provides extremely long-lived Bloch oscillations with little degradation. Such robust oscillations can be observed for a broad range of parameters and even for moderate nonlinearities and large enough force gradients. We also present an approximate analytical description for the wave packet evolution featuring a hybrid Bloch oscillating wave-soliton behavior that excellently corresponds to the direct numerical simulations.

Q 36.8 Wed 16:30 P 11

Breathers in nonlinear metamaterials with amplification and absorption — •Sascha Böhrkircher, Sebastian Erfort, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

$\mathcal{PT}$-symmetry originates from non-Hermitian quantum mechanics in the presence of gain and loss, and was experimentally proven in analogous optical systems. Recently, $\mathcal{PT}$-symmetry was realized in metamaterials. As examinations have shown, a $\mathcal{PT}$-symmetric nonlinear dimer chain composed of split-ring resonators can form discrete breather oscillations [1]. Previous works have been limited to one-dimensional systems. In our work we extend the one-dimensional dimer chain to a two-dimensional dimer surface and investigate the breather oscillations of this system starting from the one-dimensional solution. We study the behaviour of these breather oscillations by adiabatically increasing the coupling parameters.

[1] N. Lazarides and G. P. Tsironis, Phys. Rev. Lett **110**, 053901 (2013)

Q 37: Ultracold Plasmas and Rydberg Systems

Time: Wednesday 14:30–16:45 Location: P 104

Group Report Q 37.1 Wed 14:30 P 104

Non-equilibrium dynamics of dipolar interacting Rydberg spins — •Adrien Signoles[1], Miguel Ferreira-Cao[1], Asier Pineiro Orioli[2], Renato Ferracini Alves[1], Vladislav Gavryusev[1], Gerhard Zürn[1], Jürgen Berges[2], Shannon Whitlock[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Germany

Rydberg atoms in ultracold gases constitute controllable systems to experimentally study non-equilibrium phenomena, like thermalization of isolated quantum systems or relaxation after quenches. Of specific interest is the possibility to introduce resonant dipolar exchange interactions, providing new opportunities for investigating the dynamics of strongly correlated many-body quantum systems with beyond nearest-neighbour coupling.

We present an experimental realization of a prototypical dipolar spin model by coupling two strongly interacting Rydberg states by a microwave field. At low Rydberg density where interactions are negligible, we show that our system can be mapped into a spin-1/2 model, in which full control and readout are achieved by using arbitrary single-spin rotations. By driving the system out-of-equilibrium for higher densities we report the observation of coherent spin oscillations with interaction-induced damping, which can be described in terms of a dipolar XX-model in effective magnetic fields. The comparison with theoretical calculations allows us to identify the primordial quantum fluctuations as a source of relaxation.

Q 37.2 Wed 15:00 P 104

Towards a strongly interacting gas of cold strontium Rydberg atoms — Ingo Nosske[1], Luc Couturier[1], Chang Qiao[1], Fachao Hu[1], •Jan Blume[1,2], Canzhu Tan[1], Peng Chen[1], Yuhai Jiang[1,3], and Matthias Weidemüller[1,2] — [1]University of Science and Technology of China, Shanghai Institute for Advanced Studies, Xiupu Road 99, 201315 Shanghai, China — [2]Physikalisches Institut, Universität Heidelberg, Germany — [3]Shanghai Advanced Research Institute, Chinese Academy of Sciences,

We aim to create a gas of ultracold strontium Rydberg atoms. Our laser cooling strategy, with the goal of reaching temperatures and densities close to quantum degeneracy [1], involves a side-loaded 2D MOT followed by 3D broad-band and narrow-band MOTs. The strontium atoms will be excited to triplet Rydberg states via a narrow singlet-triplet intercombination line.

Here we present our latest experimental progress including the realization of our strontium 2D MOT, as well as a characterization of the locking scheme of our cooling laser which addresses the broad $5s^2\ ^1S_0 - 5s5p\ ^1P_1$ transition of strontium at 461 nm. The locking scheme is based on a commercial wavelength meter (HighFinesse

WSU10) with which an absolute frequency stability of a few MHz has been achieved.

[1] Simon Stellmer, Rudolf Grimm, and Florian Schreck. "Production of quantum-degenerate strontium gases." Physical Review A 87.1 (2013): 013611.9.5 571-586 (2014)

Q 37.3 Wed 15:15 P 104

Spectroscopy of Rydberg states in ultra cold ytterbium — •Christian Halter, Mustafa Jumaah, Laura Sucke, Tobias Franzen, Bastian Pollklesener, Cristian Bruni, and Axel Görlitz — Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Deutschland

In recent years Rydberg atoms with their special features, like dipole-dipole interaction or van-der-Waals blockade, have become more and more important for quantum optics. Particularly ultra cold Rydberg atoms are of great interest for the investigation of long range interaction. A special feature of ytterbium is that due to its two valance electrons atoms in Rydberg state can be easily manipulated and imaged using optical fields. A first step towards studies of ultra cold ytterbium is to gain precise knowledge on the Rydberg states. Here we present a spectroscopy study of the Rydberg states of ultra cold ytterbium. For the detection of the Rydberg states we are using the induced loss of atoms in a MOT when atoms are excited to a Rydberg state. Using this method we could measure several energy levels of Rydberg states.

Q 37.4 Wed 15:30 P 104

Simulating Rydberg dressing of a one-dimensional Bose-Einstein condensate — •Graham Lochead[1,2], Marcin Plodzien[3], Julius de Hond[2], N. J. van Druten[2], and Servaas Kokkelmans[3] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimerfeld 226, 69120 Heidelberg — [2]van der Waals-Zeeman Institute, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands — [3]Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands

Rydberg dressing is the process of weakly admixing strongly interacting Rydberg-character into an otherwise weakly interacting ground state. These systems have the benefit of having strong, controllable, long-range interactions while still maintaining relatively long lifetimes. These properties have lead to many proposals for exotic many-body states/phases. In this talk I will present simulations of the influence of Rydberg dressed interactions on a 1D Bose-Einstein condensate, and show the advantages of 1D geometries over 3D for experimental observation. I will also describe a current experimental setup investigating Rydberg dressing in a 1D BEC.

Q 37.5 Wed 15:45 P 104

Photon propagation through dissipative Rydberg medium at large input rates — •Ivan Mirgorodskiy[1], Christoph Braun[1,2], Florian Christaller[1,2], Christoph Tresp[1,2], Asaf Paris-Mandoki[1], and Sebastian Hofferberth[1,2] — [1]5. Phys. Inst. and Center for Integrated Quantum Science and Technology, Stuttgart University, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Department of Physics, Chemistry and Pharmacy, University of Southern Denmark, 5230 Odense M, Denmark

In our experiment we study the propagation of photons through cold atomic ensemble of 87Rb. Coupling photons to a Rydberg state via Electromagnetically Induced Transparency (EIT) leads to excitation of hybrid atom-photon states called Rydberg polaritons. Rydberg polaritons propagate through the atomic medium with vastly reduced speed and therefore strong Rydberg-Rydberg interaction can be mapped onto the photons. Thereby dissipative Rydberg-EIT media reveal a rich physics, understanding of which is of a high necessity.

In this work we investigate the particular case of large input photon rates and study quantum many-body dynamics of a dissipative Rydberg-EIT medium. We discuss effects of polariton propagation resulting in the change of photon transmission through the medium and an effect of "Rydberg pollution" consisting in a drastically increased rate of production of stationary Rydberg excitations inside of the medium.

Q 37.6 Wed 16:00 P 104

Rydberg excitation of cold atoms in hollow core fiber — •Mohammad Noaman, Maria Langbecker, Chantal Voss, Maik Selch, Florian Stuhlmann, and Patrick Windpassinger — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Cold atoms confined inside hollow-core fibers represent 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. Due to dipole blockade polaritons are restricted to a quasi one dimensional structure. Using this scheme, novel photonic states, eg crystallization of photons can be observed with possible applications in quantum information and simulation. This talk will review the current status of our experimental setup where laser cooled Rubidium atoms are transported into a hollow-core fiber using optical lattice. We present the first result of Rydberg EIT of cold atoms inside a hollow core fiber and discuss the progress towards physics in a quasi-one-dimensional geometry of Rydberg atoms.

Q 37.7 Wed 16:15 P 104

Mixed spin character bound states in ultra-long range giant dipole molecules — •Thomas Stielow, Markus Kurz, and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Str. 23-24, 18059 Rostock

An exotic species of Rydberg atoms in crossed eletric and magnetic fields are so-called giant-dipole atoms [1]. They are characterized by an electron-ionic core separation in the range of several micrometers, leading to huge permanent dipole moments of several hundred thousand Debye. Recently, diatomic molecular states formed by the binding of a giant-dipole atom with a neutral ground-state perturber have been analyzed within the framework of a triplet dominated S-wave Fermi-pseudopotential approach [2]. In this work, we expand this analysis by including both S- and P-wave scattering potentials along with the hyperfine-structure coupling of the ground-state perturber. We discuss the effects of these couplings on the adiabatic molecular potentials. In addition to the Fermi-pseudopotential ansatz we provide a comparative study based on a Green's function approach [3].

[1] Dippel O., Schmelcher P. and Cederbaum L. S., *Phys. Rev. A*, **49** (1994) 4415.

[2] Kurz, M., Mayle, M. and Schmelcher, P., *Europhys. Lett.*, **97** (2012) 43001.

[3] Fey, C., Kurz, M., Schmelcher, P., Rittenhouse, S. T., Sadeghpour, H. R., *New J. Phys.* **17** 055010 (2015).

Q 37.8 Wed 16:30 P 104

Strong coupling of a Rydberg super atom to a propagating light mode — •Jan Kumlin[1], Asaf Paris-Mandoki[2], Christoph Braun[2], Christoph Tresp[2], Sebastian Hofferberth[2], and Hans Peter Büchler[1] — [1]Institut für Theoretische Physik III and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Germany — [2]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Germany

Strong coupling of a single atom to a light mode is at the heart of quantum optics. Such systems have so-far been realised experimentally in optical cavities, but recent experimental progress in coupling propagating photons to an atomic cloud with Rydberg states enables the realisation of strong interactions between individual photons in free space and opens up a novel toolbox for quantum optics.

In this talk, we present the exact input-output formalism to describe the phenomenon of collective Rabi oscillations in a single Rydberg two-level superatom coupled to a photon field. The photonic mode defines an effective one-dimensional system, while the large size of the atomic cloud provides a chiral coupling. Using a master equation approach and the quantum regression theorem, we calculate the intensity as well as the second-order correlation function for the outgoing field by numerically solving the quantum master equation. Finally, we compare our findings with recent experimental results.

Q 38: Quantum Gases: Bosons V

Time: Wednesday 14:30–16:45 Location: P 204

Q 38.1 Wed 14:30 P 204

Observation of Quantum Criticality and Luttinger Liquid in One-dimensional Bose Gases — •Bing Yang[1,3], Yang-Yang Chen[2], Yong-Guang Zheng[1,3], Hui Sun[1,3], Han-Ning Dai[1,3], Xi-Wen Guan[2,4], Zhen-Sheng Yuan[1,3], and Jian-Wei Pan[1,3] — [1]Hefei National Laboratory for Physical Science at Microscal and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [2]State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan Institute of Physics and Mathematics, Chinese Academy of Science, Wuhan 430071, Wuhan — [3]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [4]Department of Theoretical Physics, Research School of Physics and Engineering, Australian National University, Canberra ACT 0200, Australia

We report an observation of quantum criticality and the TLL in a system of ultracold ^{87}Rb atoms within 1D tubes. The universal scaling laws are measured precisely and the characteristic critical temperatures are determined by the double-peak structure of specific heat, confirming the existence of three phases: classical gas, quantum critical region and the TLL. The Luttinger parameter estimated from the observed sound velocity approaches the measured Wilson ratio (WR), which reveals the collective nature of the TLL and the quantum fluctuations.

Q 38.2 Wed 14:45 P 204

Spatial first-order correlations of a trapped two-dimensional photon gas — •Tobias Damm, David Dung, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Bose-Einstein condensation was observed for ultracold atoms, polaritons, and more recently with photons in a dye-filled optical microcavity. In the latter experiment, the used short cavity provides a low frequency cutoff with a quadratic dispersion relation. Photons thermalize by repeated absorption and emission processes on dye molecules.

Here we report measurements of the first-order spatial coherence of the thermalized photon gas trapped in the dye microcavity, both in the classical Boltzmann regime as well as in the condensed phase. The dye microcavity emission is analyzed with a Michelson interferometer utilizing a cat eye retroreflector replacing one of the plane reflecting mirrors. Below condensation threshold correlations are determined by the thermal de Broglie length. We observe the expected $1/\sqrt{T}$ dependence with temperature, which verifies the thermal character. The onset of Bose-Einstein condensation agrees with the assumption that quantum statistical effects emerge when the thermal de Broglie wavepackets overlap, a property so for verified only for material gases. Above this critical phase-space-density we observe long range order, with the correlation length eventually exceeding the size of the condensate.

Q 38.3 Wed 15:00 P 204

Thermalized Light in Variable Micropotentials and Coupled Photon Condensates — •David Dung[1], Christian Kurtscheid[1], Tobias Damm[1], Erik Busley[1], Fahri Emre Öztürk[1], Julian Schmitt[1], Frank Vewinger[1], Jan Klärs[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn — [2]Institut für Quantenelektronik, ETH Zürich

We report work creating multiple coupled photon condensates in a single microcavity setup at room-temperature. In general, Bose-Einstein condensation has been observed for cold atomic gases, solid state quasiparticles as exciton-polaritons, and more recently with photons. The latter can be realized in a dye-filled optical microcavity. Number-conserving thermalization of photons in the dye-microcavity is achieved by multiple absorption and fluorescence processes on dye-molecules.

The microcavity creates a suitable ground state for condensation, equivalent to a non-vanishing effective photon mass. By locally thermo-optically changing the refractive index inside the microcavity an effective trapping potential for photons can be induced. For this, a focused external control laser beam locally heats an absorbing layer below one of the cavity mirror coatings, leading to a local refractive index change of a thermo-responsive polymer mixed with the dye solution. We show that Bose-Einstein condensation can be realized in such a micropotential. Moreover a thermo-optical photon self interaction is observed. Finally we show measurements on the coupling of two microsites in a double well potential for light, showing both hybridization of Eigenstates and coherent oscillations.

Q 38.4 Wed 15:15 P 204

Droplet Formation in Quantum Ferrofluids in Ring Trap Geometry — •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], the Rosensweig instability was observed in a quantum ferrofluid of a strongly dipolar BEC, leading to a formation of atomic droplets. In Ref. [2] it was demonstrated that the stability of such droplets is due to 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 this approach to study the droplet formation in a ^{164}Dy BEC in ring trap geometry where, after a sudden reduction of the scattering length, the dipolar quantum gas creates a droplet ring. We use extensive numerical simulations in order to study various properties of the emerging droplets, such as their number, size, and distribution. We also study how a phase imprinting affects the droplet formation process.

[1] H. Kadau, et al., Nature **530**, 194 (2016).
[2] L. Chomaz, et al., Phys. Rev. X **6**, 041039 (2016).
[3] T. D. Lee, K. Huang, and C.N. Yang, 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 38.5 Wed 15:30 P 204

Observation of parametric resonances in 1D shaken optical lattices — •Karen Wintersperger[1,2], Jakob Näger[1,2], Martin Reitter[1,2], Ulrich Schneider[3], and Immanuel Bloch[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstr. 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching — [3]University of Cambridge, Cambridge, UK

We study a BEC of 39K with tunable interactions in a shaken 1D optical lattice. Due to the interplay between the external drive and interactions dynamical instabilities arise [1]. The short-time dynamics can be captured by parametric resonances within Bogoliubov theory, which should lead to a fast decay of the BEC. At long times, the behavior will be dominated by collision processes described by a Fermi's Golden rule approach that slow down the decay. Varying the shaking parameters and interactions, we observe the transition between the two heating regimes. Moreover, we can identify the onset of the parametric instabilities at short times by analysing the 2D quasimomentum distribution of the excited atoms.

[1] S. Lellouch et al., arXiv: 1610.02972v1 (2016)

Q 38.6 Wed 15:45 P 204

Observation of scaling in the coarsening dynamics of a quenched one-dimensional spinor Bose-Einstein condensate — •Maximilian Prüfer, Christian-Marcel Schmied, Philipp Kunkel, Daniel Linnemann, Anika Frölian, Helmut Strobel, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg

Coarsening dynamics features a scaling behaviour of the characteristic length scale as a function of time. Accessing experimentally the corresponding scaling exponent, we employ a Bose-Einstein condensate of ^{87}Rb in the $F = 1$ hyperfine manifold with ferromagnetic interaction. We prepare the system in the polar phase and quench it into the symmetry broken ferromagnetic phase. After a build-up of excitations in the transversal spin, as predicted by Bogoliubov theory, we observe a self-similar coarsening evolution with a characteristic power-law behaviour for long evolution times. By rescaling the spatial correlation functions we determine the scaling exponent z describing the temporal evolution of the characteristic length scale.

Q 38.7 Wed 16:00 P 204

Towards a Photon Bose-Einstein Condensate in the Vacuum-Ultraviolet Spectral Regime — •Christian Wahl, René Nettekoven, Julian Schmitt, Frank Vewinger, and Martin Weitz — University of Bonn, Germany

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 propose 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 60 bar will be created inside the cavity. Using the heavy noble gases xenon and krypton, emission wavelengths in the 120-160 nm regime seem feasible. Current experimental work focuses on verifying the fulfillment of the thermodynamic Kennard-Stepanov frequency scaling between absorption and emission for the dense noble gas medium. The current status of experimental work will be reported. References: [1]: J. Klaers et al. Nature **468**, 545-548 (2010)

Q 38.8 Wed 16:15 P 204

Fluctuation-dissipation relations in a Bose-Einstein condensed photon gas coupled to a dye reservoir — •Fahri Emre Ozturk, Tobias Damm, David Dung, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Bose-Einstein condensation, the phase transition of bosons to a macroscopically occupied ground state at low temperature, has been observed e.g. in cold atomic gases and semiconductor exciton-polaritons. We have previously observed Bose-Einstein condensation of a two dimensional photon gas in a dye filled optical microcavity [1]. The photon condensate shows grand canonical statistical behavior as the condensate exchanges both energy and particles with the dye reservoir. This results in photon number fluctuations, which can be as large as the average condensate photon number [2]. In thermal equilibrium, such fluctuations are related to the linear response of the system to a weak perturbation and thermal energy k_BT. This relation, expressed by the fluctuation-dissipation theorem, also explains e.g. the Brownian motion of suspended microscopic particles. Fluctuation-dissipation relations based on particle number fluctuations have not been studied previously in Bose-Einstein condensates. Here, we report on the status of current experimental work aiming at a study of the fluctuation-dissipation theorem for a condensed photon gas coupled to a dye reservoir.

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

Q 38.9 Wed 16:30 P 204

Quantum Gases in Microgravity: Activities at ZARM — •Lisa Woerner[1], Jens Grosse[1], Michael Elsen[1], Norman Guerlebeck[1], Claus Braxmaier[1,2], and the QUANTUS collaboration[1,2,3,4,5,6] — [1]ZARM, University of Bremen — [2]DLR — [3]Humboldt University Berlin — [4]Leibniz University Hanover — [5]Ferdinand-Braun Institute — [6]Johannes Gutenberg University Mainz

This paper shall give a summary on the recent and future developments of the experiments with quantum gases in microgravity and space. The current status of the ongoing activities will be presented, possible applications explained, and further opportunities and plans introduced.

Ever since the experimental realization of the first Bose-Einstein condensate in 1995, various experiments have been developed to study the resulting cloud of atoms. Especially interest in matter wave interferometry has risen recently. The atoms are subjected to diffraction gratings and the resulting states are measured.

At ZARM different approaches to perform atom interferometry in microgravity are investigated. First experiments were performed using the drop-tower at ZARM. Succeeding these successful campaigns, the capsule containing the atom interferometer has been adapted to fit a sounding rocket.

Q 39: Ultracold atoms and BEC - IV (with A)

Time: Wednesday 14:30–16:30 Location: N 1

Q 39.1 Wed 14:30 N 1

Bosonic many-body systems with topologically nontrivial phases subject to gain and loss — •Felix Dangel, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart

Topology has emerged as a powerful tool leading to deeper insights into the classification of phases of matter. Ultracold atoms in optical lattices provide a toolbox for engineering and investigating various models with interesting topological properties. We focus on Bosonic many-body systems such as the one-dimensional superlattice Bose-Hubbard model, which exhibits topologically nontrivial phases. Edge states at open boundaries are an indicator of such phases and numerical evidence for their occurrence in the topologically nontrivial Mott-insulating phase with half-integer filling as well as a possible experimental realization have been provided in a recent work [1]. Addressing the question how edge-states are influenced when the system is extended to an open quantum system, we combine the one-dimensional superlattice Bose-Hubbard model and non-Hermitian $\mathcal{PT}$-symmetric potentials which are capable of effectively describing quantum systems with balanced gain and loss.

[1] Grusdt et al., Phys. Rev. Lett. **110**, 260405 (2013)

Q 39.2 Wed 14:45 N 1

Characterization and investigation of topologically nontrivial states in $\mathcal{PT}$-symmetric many-body systems — •Marcel Wagner, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart

$\mathcal{PT}$-symmetric quantum mechanics allows for an effective description of open quantum systems with variable particle numbers. $\mathcal{PT}$-symmetry of the quantum state ensures a purely real energy spectrum. Topologically nontrivial phases are known to occur in such many-body systems. However, their characterization is not yet well understood and raises open questions. We investigate ways to characterize topologically nontrivial phases in $\mathcal{PT}$-symmetric quantum systems. The purpose of our work is to classify these phases by searching for appropriate topological invariants.

Q 39.3 Wed 15:00 N 1

Exotic energy bands and topological phases in systems with oscillatory long-range potentials — Beatriz Olmos Sánchez[1,2], Robert J. Bettles[3], Igor Lesanovsky[1,2], and •Jiří Minář[1,2] — [1]School of Physics and Astronomy, University of Nottingham, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Non-equilibrium Quantum Systems, University of Nottingham, United Kingdom — [3]Joint Quantum Center (JQC) Durham-Newcastle, Department of Physics, Durham University, United Kingdom

The effective interaction between neutral atoms mediated by virtual photon exchange in general leads to a non-trivial long-range potential featuring both attractive and repulsive interaction [1,2] which goes beyond the typically considered simple power-law (dipolar, Van der Waals) potentials. Considering the full potential in two dimensions (which becomes relevant for atomic separations comparable to the atomic transition wavelength, situation achievable e.g. with strontium atoms), we show that it gives rise to energy spectrum with one-sided divergences in the Brillouin zone. This apparently unphysical situation is a consequence of the superextensivity of the potential and the thermodynamic limit. We perform a study for finite size systems and find new topological phases absent in the dipolar case. Moreover, the shape of the potential leads to a novel situation where energy peaks in the spectrum of arbitrary height and position can be created. Finally, we discuss the relation between the bulk and the edge states in case of square and hexagonal lattice. [1] R. H. Lehmberg, Phys. Rev. A **2** 883 (1970), [2] D. F. V. James, Phys. Rev. A **47** 1336 (1993)

Q 39.4 Wed 15:15 N 1

An Optical Quasicrystal for Ultracold Atoms — •Konrad Viebahn[1], Matteo Sbroscia[1], Edward Carter[1], Michael Höse[1],

Max Melchner[1], and Ulrich Schneider[1,2] — [1]University of Cambridge, Cavendish Laboratory, JJ Thomson Ave, Cambridge CB3 0HE, UK — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstrasse 4, 80799 Munich, Germany

We will present our experimental progress towards realising an optical quasicrystal.

A quasicrystal is a long-range ordered structure with no translational symmetry. Correspondingly, quasicrystals lie at the interface between ordered and disordered systems. On the one hand, ultracold atoms in regular (periodic) optical lattices have been studied extensively in the past years. Major achievements in this field include the first observation of the superfluid-Mott insulator transition, the realisation of the Fermi-Hubbard model, and the realisation of topological models, such as the Haldane model. On the other hand, the recent observation of many-body localisation in quasi-random optical lattices triggered another area of interest: interacting disordered systems. Now, we hope to bridge the gap between ordered and disordered systems using ultracold atoms in an optical quasilattice.

Interestingly, quasicrystals often have high rotational symmetries, five-fold or eight-fold, for example, which are forbidden in periodic crystals by the crystallographic restriction theorem. Optical lattice experiments lend themselves to realising these special geometries by superimposing lattice beams in a rotationally symmetric fashion.

Q 39.5 Wed 15:30 N 1

Quantum and thermal phase transitions in a bosonic atom-molecule mixture in a two-dimensional optical lattice — •laurent de Forges de Parny[1,4], valy rousseau[2], and tommaso roscilde[3,4] — [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 — [3]Institut Universitaire de France, 103 bd Saint-Michel, 75005 Paris, France — [4]Laboratoire de Physique, CNRS UMR 5672, École Normale Supérieure de Lyon, Université de Lyon, 46 Allée d'Italie, Lyon, F-69364, France

Recent progress in ultracold gases have allowed the study of multiple component bosonic systems, such as atomic and molecular mixtures. We will show that the coherent coupling of the atomic and molecular state, can lead to a novel insulating phase - the Feshbach insulator - for bosons in an optical lattice close to a narrow Feshbach resonance. This new phase appears around the resonance, preventing the system from collapsing when the effective atomic scattering length becomes negative. Surprisingly enough, the transition from condensate to Feshbach insulator has a characteristic first-order nature, due to the simultaneous loss of coherence in the atomic and molecular components. Our realistic numerical study shows that these features appear clearly in the ground-state phase diagram of e.g. rubidium 87 around the 414 G resonance, and they are therefore directly amenable to experimental observation. We also observe unconventional Berezinskii-Kosterlitz-Thouless transition when heating the superfluids.

Q 39.6 Wed 15:45 N 1

Approaching non-Abelian Lattice Gauge Theories with Quantum Information Methods — Mari Carmen Bañuls[1], Krzysztof Cichy[2,3], J. Ignacio Cirac[1], Karl Jansen[4], and •Stefan Kühn[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Goethe-Universität Frankfurt am Main, Institut für Theoretische Physik, Max-von-Laue-Straße 1, 60438 Frankfurt am Main, Germany — [3]Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614 Poznań, Poland — [4]NIC, DESY Zeuthen, Platanenallee 6, 15738 Zeuthen, Germany

Originally developed in the realm of quantum information theory, Tensor Network States and in particular Matrix Product States have proven themselves as promising candidates for the numerical exploration of lattice gauge models in recent years. In this talk, we explore a family of 1+1 dimensional SU(2) lattice gauge models, where the color electric flux is truncated at a finite value, with this method. We show how on finite lattices with open boundary conditions the gauge field can be integrated out, thus greatly reducing the degrees of freedom present in the system. This formulation might be suitable for a potential future quantum simulator and, moreover, allows to efficiently address the model numerically with Matrix Product States. Using this approach, we explore the low lying spectrum of these models and systematically study the effect of truncating the color electric flux at a finite value.

Q 39.7 Wed 16:00 N 1

Multipulse interaction quenched ultracold few-bosonic ensembles in finite optical lattices — •Simeon Mistakidis[1], Jannis Neuhaus-Steinmetz[1], and Peter Schmelcher[1,2] — [1]Zentrum fuer Optische Quantentechnologien, Universitaet Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universitaet Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

The correlated non-equilibrium dynamics following a multipulse interaction quench protocol in few-bosonic ensembles confined in finite optical lattices is investigated. The multipulse interaction quench gives rise to the cradle and a global breathing mode, which are generated during the interaction pulse and persist also after the pulse. The tunneling dynamics consists of several channels accompanying the dynamics. The majority of the tunneling channels persist after the pulse, while only a few occur during the pulse. The induced excitation dynamics is also explored and a strong non-linear dependence on the delayed time of the multipulse protocol is observed. Moreover, the character of the excitation dynamics is also manifested by the periodic population of higher-lying lattice momenta. To solve the underlying many-body Schroedinger equation we employ the Multi Configuration Time-Dependent Hartree method for Bosons (MCTDHB) which is especially designed to treat the out-of-equilibrium quantum dynamics of interacting bosons beyond the mean field and linear response approximations. The above mentioned findings pave the way for future investigations on the direct control of the excitation dynamics.

Q 39.8 Wed 16:15 N 1

Superfluidity and relaxation dynamics of a laser-stirred 2D Bose gas — •Vijay Pal Singh[1,2], Christof Weitenberg[2], Jean Dalibard[3], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]Laboratoire Kastler Brossel, Collège de France, ENS-PSL Research University, CNRS, UPMC-Sorbonne Universités, 11 place Marcelin Berthelot, 75005 Paris, France

We study the superfluid behavior of a two-dimensional (2D) Bose gas of ^{87}Rb atoms. In the experiment by R. Desbuquois *et al.*, Nat. Phys. **8**, 645 (2012) a 2D quasicondensate in a trap is stirred by a blue-detuned laser beam along a circular path around the trap center. Here, we study this experiment from a theoretical perspective. The heating induced by stirring increases rapidly above a velocity v_c, which we define as the critical velocity. We identify the superfluid, the crossover, and the thermal regime by a finite, a sharply decreasing, and a vanishing critical velocity, respectively. A direct comparison of our results to the experiment shows good agreement, if a systematic shift of the critical phase space density is included. We relate this shift to the absence of thermal equilibrium between the condensate and the thermal wings in the experiment, which were used to extract the temperature. We expand on this observation by studying the full relaxation dynamics between the condensate and the thermal cloud. Analytical results on the vortex formation are also discussed.

Q 40: Poster: Quantum Optics and Photonics II

Time: Wednesday 17:00–19:00 Location: P OGs

Q 40.1 Wed 17:00 P OGs

Coupled Photon Condensates in Micropotentials — •Erik Busley, Christian Kurtscheid, Christian Schilz, David Dung, Tobias Damm, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

We present a recent experimental realization of coupled photon condensates in a microstructured optical microcavity. In earlier work we have realized Bose-Einstein condensation of photons in a dye-filled optical microcavity at room temperature. The dye solution acts both as a heat bath and a particle reservoir for the trapped photon gas. Thermal contact between the photons and the molecules is achieved by subsequent absorption and reemission processes in the high-finesse bispherical cavity. The microresonator introduces a low-frequency cutoff to the dispersion relation, resulting in a nontrivial ground state and the harmonically trapped photon gas becomes formally equivalent to a 2D gas of massive bosons.

In the here reported work, the cavity geometry is controlled by permanently deforming an initially plane mirror surface by thermo-optically induced delamination of the dielectric layers. Heat deposited by an absorbed green laser beam causes the mirror surface to bend up locally, and by transverse steering of the laser beam over the mirror surface one can create arbitrary trapping potentials for a photon gas within the microcavity. The deformation setup and measurements on photon tunneling between two lattice sites are presented.

Q 40.2 Wed 17:00 P OGs

Bose-Hubbard ladder in a cavity-induced artificial magnetic field — •Catalin-Mihai Halati, Ameneh Sheikhan, and Corinna Kollath — HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

We consider ultra-cold 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 tunnel along the leg direction and collect a spatial phase imprint during the tunneling along a rung. The phase imprint is realized via Raman transition 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, which needs to be analyzed self-consistently. We characterize the system by performing a Bogoliubov theory for quasiparticles excitations on top of the bosonic condensate, whose spectrum has characteristic features of the superfluid phase. In this framework we solve the self-consistency condition and identify the steady states that can occur.

Q 40.3 Wed 17:00 P OGs

Non-equilibrium dynamics of interacting Bosons in an optical lattice — •René Hamburger[1], Christian Baals[1,2], Bodhaditya Santra[1,3], Jian Jiang[1], Ralf Labouvie[1,2], Andreas Müllers[1], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Staudinger Weg 9, 55128 Mainz, Germany — [3]Zentrum für optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany

We study the non-equilibrium dynamics of ultracold Bose gases in optical lattices using a scanning electron microscope. In a first experiment we remove the atoms from a slice of a 3D optical lattice and study the subsequent refilling dynamics of different lattice configurations. We observe a transition from a superfluid refilling to the hopping dynamics of a Mott insulator. The latter strongly depends on the filling level of the lattice sites: a n=1 Mott insulator moves in a single-particle hopping process, whereas a n=2 shell can only tunnel via second-order processes. Furthermore, we investigate the dynamics of the center of mass in a three dimensional optical lattice. To this end we shift the position of the confining dipole trap after loading the atoms into the lattice. Finally the atomic cloud is imaged with high resolution using electron microscopy. Upon increasing the lattice depth we find a transition from an oscillating superfluid to a slow uniform movement in the Mott regime. Additionally we present our future project on dissipative generation and stabilization of a dark soliton in 3D.

Q 40.4 Wed 17:00 P OGs

Real-time observation of a quantum phase transition between two insulators — •Nishant Dogra, Lorenz Hruby, Katrin Kröger, Manuele Landini, Tobias Donner, and Tilman Esslinger — HPF D4, Quantum Optics Group, Institute for Quantum Electronics, ETH Zurich,Otto-Stern-Weg-1,Zurich-8093

The phase transition between two insulating phases with different density ordering is thermodynamically possible but can be blocked due to the existence of energy barriers between various stationary states. We explore such a phase transition in a lattice model with competing onsite and global-range interactions in a Bose-Einstein Condensate (BEC). The global-range interactions arise from the coupling of the BEC to a single mode of a high-finesse cavity and illuminating it with a transverse laser-field. In the limit of deep optical lattices, the system favors either a Mott insulator or a charge density wave insulator depending on the relative interaction strength which is tuned via the cavity resonance. The corresponding order parameter can be detected in real time via the cavity light field. We observe a hysteretic loop in the transition between two insulators which we attribute to the existence of metastable states in the system. Moreover, the temporal dynamics of the order parameter across the transition exhibits two different time scales due to the presence of compressible surface states in our system.

Q 40.5 Wed 17:00 P OGs

Nonthermal Fixed Points and Universal Scaling in Ultracold Bose Gases far from Equilibrium — •Markus Karl[1,2] and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Universal spatio-temporal scaling behaviour is studied in the dynamics of isolated and driven-dissipative Bose gases by means of semi-classical stochastic simulations of the Gross-Pitaevskii model. The system is quenched far out of equilibrium by means of instabilities, by directly imprinting vortex defects, or by applying a stochastic driving force. We demonstrate that, under these non-equilibrium conditions, the long-time dynamics is mainly determined by nonthermal fixed points, close to which universal scaling laws are realised for time-dependent correlation functions. In particular, we find that the time evolution of single-particle occupation spectra is given by a scaling transformation of universal scaling functions. We determine the corresponding scaling exponents by means of numerical simulations and interpret them in the light of field-theoretic predictions. We analyse the relation of the identified temporal scaling laws to phase ordering kinetics and coarsening of vortex defect distributions, thereby relating phenomenological and analytical approaches to classifying far-from-equilibrium scaling dynamics with each other. Moreover, the relation to superfluid turbulence as well as to driven stationary systems is discussed.

Q 40.6 Wed 17:00 P OGs

Quantum Phases in an Extended Bose-Hubbard Model with Global-Range Interactions — •Katrin Kröger[1], Renate Landig[1,2], Lorenz Hruby[1], Nishant Dogra[1], Manuele Landini[1], Rafael Mottl[1], Tobias Donner[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA 02138, USA

Quantum simulations with ultracold atoms have for a long time been limited to short-range collisional interactions, as long-range interactions have proven to be difficult to implement. Here, we experimentally realize an extended Bose-Hubbard model with long-range interactions using an atomic quantum gas trapped in a three-dimensional optical lattice and coupled to a single mode of a high finesse optical cavity. The strength of the short-range on-site interactions is controlled through the optical lattice depth. The vacuum mode of the cavity mediates a global-range interaction in the presence of a transverse laser beam. The corresponding strength can be tuned by shifting the frequency of the cavity resonance with respect to the frequency of the transverse pump beam. The interplay of tunneling, short- and global-range interactions leads to a rich phase diagram. We observe the appearance of four distinct phases, namely a superfluid, a supersolid, a Mott insulator and a charge density wave.

Q 40.7 Wed 17:00 P OGs

Bottom-up approach to many-body physics with ultracold atoms in adjustable lattices — •Martin Sturm, Malte Schlosser, Gerhard Birkl, and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt

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. 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 from measurements and simulations of the light field. Further, we investigate the time scales and heating mechanisms for loading from a Bose-Einstein condensate as well as from a low entropy state in the deep Mott insulator regime. As a possible application we analyze the tunneling dynamics between two coupled ring lattices. This configuration exhibits additional many-body resonances as compared to bosonic Josephson junctions in double-well potentials.

Q 40.8 Wed 17:00 P OGs

Non-equilibrium dynamics of an interacting Fermi gas — •Johannes Kombe, Jean-Sébastien Bernier, and Corinna Kollath — HISKP, Universität Bonn

Thanks to recent experimental 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 the recent progress, we investigate theoretically the evolution of a trapped three-dimensional Fermi gas during a slow interaction change. Our study, carried out on the BCS side, reveals various collective excitations.

Q 40.9 Wed 17:00 P OGs

Towards a lithium quantum gas microscope for small quantum systems — •Andreas Kerkmann, Michael Hagemann, Jan Mika Jacobsen, Justus Brüggenjürgen, Malte Hagemann, Benno Rem, Christof Weitenberg, and Klaus Sengstock — Institut für Laserphysik, Hamburg, Germany

We are setting up a new quantum gas microscope for the preparation and detection of degenerate samples of ^{6}Li/ ^{7}Li atoms to study strong correlations in small quantum systems. Our design is optimized for a short cycle time allowing good statistics even in the case of just a few atoms. It consists of a compact 2D-/ 3D-MOT chamber aiming for an all-optical preparation of degenerate samples. In our poster, we provide information about details of the design and the current status of the experiment.

Q 40.10 Wed 17:00 P OGs

Measuring transport properties of a quantum point contact for cold atoms — •Dominik Husmann[1], Martin Lebrat[1], Samuel Häusler[1], Sebastian Krinner[1], Laura Corman[1], Jean-Philippe Brantut[2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, Switzerland — [2]Institute of Physics, EPFL Lausanne, Switzerland

Quantum point contacts (QPCs) featuring quantization of conductance are fundamental components for mesoscopic nanostructures. Here we study the evolution of quantized conductance with interaction strength across the BEC-BCS crossover in ultracold fermions. Our system is a two-terminal setup of lithium 6 atoms in two different hyperfine states, connected by an optically tailored QPC. We impose independently a spin or particle imbalance between the reservoirs, creating a restoring drive that allows to measure spin and particle conductance. With increasing attractive interactions we find a plateau in the particle conductance at values larger than the expected quantum of 1/h. Subsequently we observe an onset of superfluidity manifested in a abrupt increase of the conductance with density. The superfluid gap causes a suppression of spin excitations, which we see in a non-monotonous behavior in spin conductance as a function of density. Complementary to creating particle and spin bias, we can apply a temperature gradient between the reservoirs. The thermoelectric response of the system is an interplay between QPC and reservoir contributions. The high tunability of our system opens up a wide parameter range to study thermoelectricity through a QPC.

Q 40.11 Wed 17:00 P OGs

Spin- and density-resolved microscopy of antiferromagnetic correlations in Fermi-Hubbard chains — •Joannis Koepsell[1], Timon Hilker[1], Guillaume Salomon[1], Martin Boll[1], Ahmed Omran[1], Jayadev Vijayan[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institute für Quantenoptik — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, München

Important aspects of the puzzling physics of the doped Hubbard model are believed to be rooted in the complex interplay between magnetism in the spin sector and correlations in the density sector. A quantum simulator that at the same time resolves the spin and density degrees of freedom and thus allows to measure correlations between them would be a perfect tool to explore these systems. Here we report on details of the realization of such a quantum gas microscope for fermionic Lithium. Furthermore, we summarize recent measurements revealing antiferromagnetic correlations in 1d Hubbard chains. By a comparison to Quantum-Monte-Carlo simulations we infered an entropy below ln(2) at which longer ranged correlations emerge. Additionally, we report on ongoing measurements of spin-density correlations in doped systems and our progress with two dimensional systems.

Q 40.12 Wed 17:00 P OGs

Observing the hierarchy of energy scales in a periodically driven two-body system — •Kilian Sandholzer, Rémi Desbuquois, Michael Messer, Frederik Görg, Gregor Jotzu, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, Zürich, Switzerland

Applying time-periodic potentials is a very useful tool to experimentally realize exotic Hamiltonians. In the framework of Floquet theory the physics is described by slow dynamics of an effective Hamiltonian and the micromotion. By loading a two-component Fermi gas in an array of modulated double-wells we realize a driven building block of the Hubbard model. Measuring the number of doubly occupied sites and the spin-spin correlation the micromotion of the driven system is revealed and compared to theory. Tuning the interaction near to the driving frequency leads to an increased coupling to higher states. Here, we investigate whether the groundstates of the static and effective Hamiltonians are adiabatically connected. We show a regime where we are able to prepare and measure Floquet engineered Hamiltonians beyond the high-frequency expansion in an interacting two-particle system.

Q 40.13 Wed 17:00 P OGs

Controlling magnetic exchange couplings in periodically driven systems — •Michael Messer, Frederik Görg, Gregor Jotzu, Kilian Sandholzer, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, Switzerland

Floquet engineering can be used to implement effective Hamiltonians that reach beyond the Hubbard model. By modulating the lattice position of an interacting system on an array of double wells we implement a Floquet Hamiltonian with controllable magnetic exchange energy. When shaking at a frequency slightly detuned to the interaction energy we can use the shaking amplitude to tune the strength of the magnetic exchange independently of the single particle tunneling. In addition Floquet engineering enables us to switch from static anti-ferromagnetic behavior to a ferromagnetic coupling within our fermionic system. We furthermore implement our scheme for interacting many-body systems and address the question whether experimental timescales are favorable to adiabatically connect states of the driven system to the initial states.

Q 40.14 Wed 17:00 P OGs

Exploring Quantum Antiferromagnets with single-site resolution — •Daniel Greif, Anton Mazurenko, Christie S. Chiu, Geoffrey Ji, Maxwell F. Parsons, and Markus Greiner — Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Strongly correlated electron systems are at the center of many poorly understood phenomena in condensed matter systems, including high-temperature superconductivity, which is thought to be well described by the Hubbard model. Ultracold fermionic atoms trapped in a 2D layer of a square lattice provide a clean and tunable implementation of the Hubbard model. Optical microscopy on these systems permits an unprecedented degree of control and detection unavailable in traditional condensed matter systems. We report site-resolved measurements of strongly interacting many-body states, including 2D fermionic Mott insulators and band insulators. We further report site-resolved measurements of the spin correlation function in these samples, exhibiting antiferromagnetic correlations. High fidelity addressing with a digital micromirror device permits exploration of previously inaccessible regions of the Hubbard model at temperatures below the 3D Neel transition temperature. We detect the presence of antiferromagnetic long-range order at temperatures $T/t = 0.25$ directly from a peak in the spin structure factor, corresponding to a finite staggered magnetization, and a diverging correlation length of the spin correlation function. Our results open the path for a controlled study of the low-temperature phase diagram of the Hubbard model.

Q 40.15 Wed 17:00 P OGs

Gray molasses cooling of ^{6}Li towards a double-degenerate

^{133}**Cs-**^{6}**Li Bose-Fermi mixture** — •Manuel Gerken, Stephan Häfner, Binh Tran, Melina Filzinger, Bing Zhu, Juris Ulmanis, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

An ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li is an ideal system for the study of Efimov's scenario as well as polarons due to its large mass imbalance and the tunability of intra- and interspecies interactions via Feshbach resonances. Gray molasses on the D1 line of ^{6}Li is newly implemented in the experiment as a further cooling step after Doppler cooling in the MOT. We achieve Sub-Doppler temperatures of down to 42 μK with almost unit capture efficiency. This leads to a tenfold improvement in phase-space density and therefore better starting conditions for the generation of a double-degenerate Bose-Fermi mixture.

Q 40.16 Wed 17:00 P OGs

Laser Cooling in a Parabolic Mirror — •Thorsten Haase, Nils Trautmann, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt

The efficient coupling of light to single quantum receivers is of high interest in quantum optics and quantum communication. In current experiments coupling inside a parabolic mirror is investigated [1]. We propose a semiclassical theory for laser cooling inside the parabolic mirror which includes both standing waves and strongly focused waves. Our treatment predicts relevant deviations from the usual case of Doppler cooling which typically considers plane running waves only. These generalisations affect the motion of the particle and lead to different probability density functions inside the trap. Stochastic simulations are presented for the probability density function. First one-dimensional simulations show that the steady states inside the parabolic mirror deviate from Gaussian or thermal distributions, which are predicted by the theory of Doppler cooling with plane waves. This could explain recent experimental results. Also, we present three-dimensional simulations investigating these effects for more realistic setups.

[1] M. Fischer, M. Bader, R. Maiwald, A. Golla, M. Sondermann, and G. Leuchs, Applied Physics B 117 (2014)

Q 40.17 Wed 17:00 P OGs

New apparatus for laser cooling and trapping of Dy and K atoms — C. Ravensbergen[1,2], S. Tzanova[1,2], M. Kreyer[2], •E. Soave[2], A. Werlberger[2], V. Corre[1,2], E. Kirilov[2], and R. Grimm[1,2] — [1]IQOQI, Austrian Academy of Sciences, Innsbruck, Austria — [2]Insitute for Experimental Physics, University of Innsbruck, Innsbruck, Austria

We have developed a new apparatus for producing mixtures of dysprosium and potassium atoms. Atoms of K are first cooled with a 2D^{+} MOT, which reduces the transverse velocities. A beam propagating along the longitudinal direction pushes atoms into the main chamber, where they are trapped in a 3D magneto-optical trap. We have achieved both a MOT of the bosonic ^{39}K and fermionic ^{40}K isotope. A Dy atomic beam is created in a high-temperature effusion oven, it is then slowed in a combination of transverse cooling and a Zeeman slower. In the main chamber atoms are trapped in a narrow-line 3D MOT. The beams with a 40 mm diameter are tuned to the 136 kHz linewidth transition at 626 nm. Because of the narrowness of the line, the laser is locked onto a high-finesse cavity. The lasers for the Dy MOT and for K are all fiber-laser systems. This brings the advantages of a linewidth of the order of 10 kHz, high beam quality, and both high mechanical and temperature stability.

Q 40.18 Wed 17:00 P OGs

Microtrap for hybrid Rb-Yb^{+} systems — •Matthias Müller[1], Abasalt Bahrami[1], Jannis Joger[2], Rene Gerritsma[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Institute of Physics, Universiteit van Amsterdam

Mixtures of ultracold atoms and trapped ions [1] form interesting platforms for studying cold chemistry, cold collisions, polaron physics, but also quantum information and quantum simulation with strong links to condensed matter physics [2]. We have designed and fabricated a combined atom and ion trap based on modern chip trap technology that employs strong inhomogeneous magnetic fields generated by integrated electromagnets to trap the atoms. Such tight magnetic traps will allow wavepacket sizes of the atoms in the range of the atom-ion interaction range. Straight-forward magnetic field control should make it possible to resolve the atom-ion interaction with sub-μm precision [3].

[1] A. Härter, J. Hecker Denschlag, Cont. Phys., 55, 33 (2014).
[2] C. Zipkes, S. Paltzer, C. Sias and M. Kohl, Nature 464, 388 (2010).
[3] J. Joger, Master thesis, University of Mainz (2013).

Q 40.19 Wed 17:00 P OGs

Spin-dependent Transport of Neutral Atoms in a 2D Polarization-Synthesized Optical Lattice — •Max Werninghaus, Stefan Brakhane, Geol Moon, Gautam Ramola, Carsten Robens, Alexander Knieps, Richard Winkelmann, Wolfgang Alt, Dieter Meschede, and Andrea Alberti — Institut für angewandte Physik Bonn

Discrete time quantum walks can be realized by deterministically transporting atoms based on their internal state. We recently reported on a new scheme for the polarization synthesis of a spindependent optical lattice that overcomes limitations of previous EOM-based setups by enabling arbitrary transport distances in a single step [1]. Here, we present an implementation extending the concept of polarization-synthesized to two dimesions, allowing spin-dependent transport in x- and ydirection [2] . The polarization synthesis to create an arbitrary polarization relies on the phase - and intensity control of two independent overlapped beams of opposite circular polarization[1]. I present the experimental realization and characterization of the opto-electronic control loops relying on a digital controller which allows us to use feedforward procedures based on internal model control.

[1] C. Robens et al: Fast, high-precision optical polarization synthesizer for ultracold-atom experiments, arXiv:1608.02410 (2016)
[2] T. Groh et al: Robustness of topologically protected edge states in quantum walk experiments with neutral atoms Phys. Rev. A (editors suggestion) **94** (2016)

Q 40.20 Wed 17:00 P OGs

Van der Waals interactions of Rydberg excitons — •Johannes Block and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Strasse 23, D-18059 Rostock, Germany

Rydberg atoms experience strong van der Waals interactions due to their large dipole moments that result in a so-called Rydberg blockade [1,2]. Similarly, Rydberg excitons in semiconductors such as Cu_2O with wavefunctions in the μm-range [3] are likely subject to strong van der Waals interactions. We apply well-known atomic calculations [2,4] to the excitonic system to obtain the Rydberg blockade. Here we show that the small level spacing including quantum defects [5] as well as the confining symmetry of the semiconductor crystal [6] provide additional contributions to the interaction.

[1] E. Urban *et al.*, Nature Physics **5**, 110 - 114 (2009).
[2] T.G. Walker, M. Saffman, Phys. Rev. A **77**, 032723 (2008).
[3] T. Kazimierczuk *et al.*, Nature **514**, 343 (2014).
[4] J. Han, Phys. Rev. A **82**, 052501 (2010).
[5] F. Schöne *et al.*, J. Phys. B **49**, 134003 (2016).
[6] H. Safari, M.R. Karimpour, Phys. Rev. Lett. **114**, 013201 (2015).

Q 40.21 Wed 17:00 P OGs

Electric field controlled collisions between polar molecules and Rydberg atoms — •Ferdinand Jarisch and Martin Zeppenfeld — Max Plank Institut für Quantenoptik, Garching

Controlling collisions and chemical reactions via external electric or magnetic fields provides unprecedented control over such processes, with applications including Feshbach association of ultracold molecules from ultracold atoms. We present electric field controlled collisions between polar molecules and Rydberg atoms. State changing collisions between polar molecules and Rydberg atoms are mediated by Förster resonant energy transfer. Changing the resonance condition via electric fields allows the collision cross section to be varied. Our work is a first step towards quantum control of hybrid molecule-Rydberg-atom systems, with possible applications including efficient nondestructive detection of polar molecules[1].

[1] M. Zeppenfeld, "Nondestructive Detection of Polar Molecules via Rydberg Atoms", Nov. 2016, arXiv:1611.08893 [physics.atom-ph]

Q 40.22 Wed 17:00 P OGs

Magnetic shielding of an atomic chip trap — •Florian Grewe and Reinhold Walser — Institut für Angewandte Physik, Technis-

che Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

In context of the QUANTUS project, degenerated quantum gases are created in weightlessness for high precision measurements. In order to achieve degeneracy, atoms have to be trapped and cooled down over several steps. A combination of coils and a carefully designed atomic chip [1, 2, 3, 4] is used to generated magnetic fields to trap, cool and manipulate the cold atomic gas. In addition to the atomic chip, there is a cylindrical mu-metal shielding to cancel the earth's magnetic field and other residual perturbations. Clearly, this shield has also an effect on the field created by the chip trap.

Here we present our analysis of the magnetic field inside the shielding leading to corrections of the atomic magnetic potential.

[1] W. Herr, Eine kompakte Quelle quantenentarteter Gase hohen Flusses für die Atominterferometrie unter Schwerelosigkeit, PhD thesis, Gottfried Wilhelm Leibniz Universität Hannover, 2013.

[2] J. Fortágh, C. Zimmermann, Rev. Mod. Phys. 79, 235 (2007).

[3] J. Schmiedmayer, et al., Adv. At. Mol. Opt. Phy. 48, 263 (2002).

[4] T. W. Hänsch, J. Reichel, et al., Nature 413, 498 (2001).

Q 40.23 Wed 17:00 P OGs

Compact and stable potassium laser system for dual-species atom interferometry in microgravity — •Julia Pahl[1], Christoph Grzeschik[1], Aline Dinkelaker[1,2], Max Schiemangk[1,2], Markus Krutzik[1], Achim Peters[1], and The QUANTUS-Team[1,3,4,5] — [1]HU Berlin — [2]FBH Berlin — [3]U Bremen — [4]LU Hannover — [5]JGU Mainz

We present a laser system for laser cooling and atom interferometry with ^{41}K atoms for future dual-species experiments in microgravity testing the Einstein equivalence principle with ultracold quantum matter. This potassium laser system will be integrated into the QUANTUS-2 drop capsule already performing atom-chip based rubidium BEC experiments at the drop tower in Bremen. Demanding limitations on mass and size due to the capsule's technical restrictions as well as strong accelerations during the catapult launch require the laser system to be compact and robust. High-power, micro-integrated distributed-feedback diode laser modules in combination with novel compact electronics allow to meet these strict requirements while keeping the output power and spectral characteristics compliant with ^{41}K BEC generation. In this poster, we present the details of our laser system, focussing on overcoming technical demands and discuss the challenges of ^{41}K featuring a hyperfine splitting comparable to the natural linewidth.

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 40.24 Wed 17:00 P OGs

Influence of external forces in near-field matter-wave interferometry — •Filip Kiałka, Benjamin Stickler, and Klaus Hornberger — Faculty of Physics, University of Duisburg-Essen, Lotharstraße 1-21, 47048 Duisburg, Germany

Molecular matter-wave interferometry is an established experimental technique with applications in precision metrology and fundamental quantum science [1]. In this work, we analyze the interference pattern observed in a generic Talbot-Lau interferometer (TLI) subject to external forces. In particular, we study the influence of the Coriolis force, which will become significant for interferometers with long flight times. We quantify the loss of interference contrast and explore the strategies to correct for the Coriolis effect in a TLI setup. Finally, we examine how the external force exerted by an electric field with a constant gradient could be used for metrological purposes.

[1] Testing the limits of quantum mechanical superpositions, M. Arndt and K. Hornberger, Nature Physics 10 (2014) 271-277

Q 40.25 Wed 17:00 P OGs

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], Markus Krutzik[1], Achim Peters[1], and The MAIUS Team[1,2,3,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand Braun Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Physik, JGU Mainz — [5]IQO, Leibniz Universität Hannover

The MAIUS II/III missions will perform dual-species atom interferometry with BEC's onboard sounding rockets, enabling longer, uninterupted timescales of microgravity than any other ground based facility. By therefore effectively increasing interferometer times beyond the typical limits imposed by, for example, the maximum height of terrestrial instruments, MAIUS II/III will allow for high-precision measurements of Einsteins's Equivalence principle.

This poster presents the design of our laser system for this mission in detail. All key components such as micro-integrated high power diode lasers, optical fiber splitter system and Zerodur bench technology will be highlighted. The laser sources are exetended cavity diode laser (ECDL) master oscillator power amplifier (MOPA) modules. They feature wavelengths of 780 nm and 767 nm for Rb and K as well as 1064 nm for a dipole trap.

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 40.26 Wed 17:00 P OGs

MAIUS-B: Towards dual species atom interferometry with Bose-Einstein condensates in space — •Baptist Piest[1], Wolfgang Bartosch[1], Dennis Becker[1], Michael Elsen[2], Kai Frye[1], Maike D. Lachmann[1], Wolfgang Ertmer[1], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, LU Hannover, Hannover, Deutschland — [2]DLR Institut für Raumfahrtsysteme, Bremen

We explore the feasibility of a quantum test of the Einstein equivalence principle with a dual species atom interferometer in space. The precision of such an experiment can be enhanced by the extended free fall of the matter waves in the interferometer. Goals of the sounding rocket mission MAIUS-2 are the generation of K-41 and Rb-87 BECs and the first demonstration of Raman based matterwave interferometry in space. The design builds on the MAIUS-A experiment [1]. The new system has been commissioned and qualified on ground and first results on ground-based cooling of alkaline atoms are presented.

[1] J. Grosse et al., J. Vac. Sci. Technol. A 34, 031606 (2016).

Q 40.27 Wed 17:00 P OGs

Demonstration of an all digital optical phase-lock for precision measurements. — •Alexandros Papakonstantinou, Thijs Wendrich, Wolfgang Bartosch, Ernst Rasel, and Wolfgang Ertmer — Institut für Quantenoptik, Universität Hannover

For many applications in quantum optics involving for example an atom interferometer, one will need lasers with a precise phase relation. The residual phase noise transfers directly to the performance of an atom interferometer. In this poster we present an all-digital optical phase-lock implemented in an FPGA. The FPGA receives a pre-scaled beat signal between two lasers and outputs an analog signal that directly drives the laser. Its firmware includes the phase frequency detector as well as the loop filter and enables an easy, software based, optimization of loop parameters for best performance in different tasks. This new phase-lock technique can enable phase-locks for tasks in quantum optics that previously used less advanced techniques, and can be used to further improve experiments like the MAIUS missions.

This work is part of the Quantus/Maius project which is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under grant number 50WM1239.

Q 40.28 Wed 17:00 P OGs

Control electronics for precision measurements on a sounding rocket. — •Wolfgang Bartosch, Thijs Wendrich, Ernst 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-1 mission will explore BEC interferometry in space. Operation on sounding rockets poses stringent requirements on the mass, volume and especially features such as reliability robustness of the payload. In this poster we show the electronics we designed to control an atom interferometer experiment on a sounding rocket. We had to downsize lab filling electronics to match the requirements on a sounding rocket both in size and toughness while maintaining its accuracy.

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 604 107 22.

Q 40.29 Wed 17:00 P OGs

Progress report towards a portable $^{27}Al^+$ optical clock — •Stephan Hannig[1], Nils Scharnhorst[1], Johannes Kramer[1], Lennart Pelzer[1], Stepanova Mariia[1], Leroux Ian D.[3], Tanja E. Mehlstäubler[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany — [3]National Research Council Canada, 1200 Ottawa, Canada

We present the status of our aluminium ion optical clock using quantum logic techniques for cooling and reading out the clock ion. The design goals for the frequency standard are an inaccuracy below 10^{-17} and relative instability better than 10^{-15} in one second. $^{27}Al^+$ provides a narrow (8 mHz) clock transition at 267 nm which exhibits no electric quadrupole shift and a low sensitivity to black-body radiation. A single $^{27}Al^+$ ion will be 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 Coulomb interaction.

A second generation, new vacuum chamber and complete Ca^+ laser system have been set up, partly using fiberized components to feature miniaturization and thereby portability. The chamber includes a segmented multi-layer linear Paul trap. This design enables the implementation of multi-ensemble, multi-ion clock protocols which can advance the stability of ion-based optical clocks.

We will use such a transportable optical clock for aplications such as relativistic geodesy.

Q 40.30 Wed 17:00 P OGs

Investigation of fast ground state cooling schemes for a trapped Ca ion — Nils Scharnhorst[1], •Johannes Kramer[1], Javier Cerrillo Moreno[2], Alex Retzker[3], Ian D. Leroux[4], and Piet O. Schmidt[1,5] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Technische Universität Berlin, 10623 Berlin — [3]The Hebrew University of Jerusalem, 91904 Jerusalem — [4]National Research Council Canada, 1200 Ottawa — [5]Leibniz Universität Hannover, 30167 Hannover

One of the major systematic uncertainties of frequency standards based on light atoms, such as the aluminium ion, is the time dilation shift from residual motion. This requires fast near-ground state cooling of all motional modes to reduce this shifts and minimise dead time between interrogations. Conventional Doppler cooling techniques typically do not achieve the required reduction in motional energy. Sideband cooling techniques achieve this goal, but typically only for a single motional mode at a time. In multi-level atoms, coherences between levels can be used to design non-Lorentzian scattering spectra that selectively suppress heating processes, promising cooling times comparable to Doppler cooling. We investigate double-EIT cooling [1], based on a tripod level scheme in a calcium ion, involving the two ground states $S_{1/2}$ and the metastable $D_{5/2}$ levels. We demonstrate simultaneous cooling of the radial and axial motional modes of a $^{40}Ca^+$ ion near to the ground state in a single, short laser pulse.

[1] Evers, J. and Keitel, C. H., *Europhys. Lett.*, **68** 370 (2004).

Q 40.31 Wed 17:00 P OGs

Precise optical bulk and surface absorption measurements in high purity silicon. — •Johannes Dickmann[1,2,3], Stefanie Kroker[1,2], Carol Bibiana Rojas Hurtado[1,2], René Glaser[3], and Ronny Nawrodt[3] — [1]Physikalisch-Technische Bundesanstalt — [2]Technische Universität Braunschweig — [3]Friedrich-Schiller-Universität Jena

Silicon is a promising material for high-precision metrological applications such as gravitational wave detectors and frequency stabilized laser systems for the realization of optical clocks. In order to maximize the performance of such experiments, the optical absorption of all involved elements should be as small as possible. This sets high demands to the purity of the utilized silicon material. For quantitative statements on the optical performance it is essential to measure the surface and bulk absorption separately. Photothermal deflection spectroscopy is a powerful tool for these measurements. In this contribution, theoretical and experimental aspects of such high resolution measurements are discussed. Numerical calculations are presented which help to estimate the influence of all parameters and thereby to optimize the experimental setup. We present results of the following measurements: Bulk absorption of silicon samples with variable doping gradients, room temperature surface absorption in dependence of surface roughness as well as temperature dependent surface and bulk absorption down to 4 K. The developed experimental setup is very sensitive to material disturbances. Therefore, an application in quality control of 2D (thin films) and 3D (bulk materials) is possible.

Q 40.32 Wed 17:00 P OGs

Asymmetry induced resonances for performance prediction of short wavelength periodic nanostructures — •Carol Bibiana Rojas Hurtado[1,2], Johannes Dickmann[1,2], Thomas Siefke[1,3], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt — [2]Technische Universität Braunschweig — [3]Friedrich-Schiller-Universität Jena

Nano-optical elements for applications at short wavelengths are subject to strict requirements with respect to structural accuracy. Even deviations in the range of a few nanometers can have a considerable impact on the optical performance of the related elements. In this contribution, we investigate asymmetry induced guided mode resonances (GMR) as a measure for structure deviations in nano-optical wire grid polarizers made of titania. Hereby, the structural asymmetry arises from the self-aligned double patterning process - a well-established technique for the realization of structures with small periods. The guided mode resonances yield information about the structure geometry and enable the prediction of the polarizer performance at short wavelengths < 200 nm. Thus, easily accessible reflectance and transmission spectral measurements at a wavelength around 370 nm can replace an elaborate optical characterization in the DUV region. An additional advantage of this method is that no calibration is necessary which promises high application potential as in-situ tool. Furthermore, the presented method can be extended to applications at even shorter wavelengths down the extreme ultraviolet spectral region as well as to 2D periodic structures of versatile shape.

Q 40.33 Wed 17:00 P OGs

Pulse shaping of single photons with pulsed cavity SPDC sources — •Simon Laibacher[1] and Vincenzo Tamma[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm, Germany — [2]Faculty of Science, SEES, University of Portsmouth, Portsmouth PO1 3QL, UK

Cavity-enhanced spontaneous parametric down conversion (SPDC) is used extensively as a light source in quantum optics. Such sources are nowadays often integrated into waveguides where high finesses cannot easily be achieved and thus reservoir theory cannot be applied to describe the coupling of the cavity. Recently, a description of such sources for arbitrary sub-threshold gain has been published for continuous pumping [1].

Our work aims to extend this description by including a finite phase matching bandwidth and allowing for a pulsed operation of the source. We derive the general Bogolioubov transformation between the input and output fields of the cavity for Type-II SPDC under these conditions. Our approach allows us to easily calculate arbitrary correlation functions of the generated two-mode state. We then use our formalism to investigate how the shape of the pump pulse and post-selection in the heralding time of the idler photons can be employed to engineer the shape of the signal photons. Further, corrections to the signal-idler cross correlation function reported in [1] are found in the limit of near-threshold squeezing.

[1] Zielińska and Mitchell, Phys. Rev. A **90**, 063833 (2014).

Q 40.34 Wed 17:00 P OGs

Optimizing the correlation signals in Hanbury-Brown-Twiss-setups — •André Pscherer, Raimund Schneider, Thomas Mehringer, Johannes Hölzl, and Joachim von Zanthier — FAU Erlangen-Nürnberg, Erlangen, Deutschland

When measuring the correlations between arrival times of photons at two detectors like in the original Hanbury-Brown and Twiss (HBT) experiment the key to satisfactory results is a good understanding of the various parameters affecting the second order photon correlation function $g^{(2)}(\vec{r}_1, \vec{r}_2, \tau)$. We discuss in particular effects like a finite detector size and limited temporal resolution and investigate how they influence the trade-off between count rates and the contrast of the $g^{(2)}(\vec{r}_1, \vec{r}_2, \tau)$-function.

Q 40.35 Wed 17:00 P OGs

Microwave quantum logic for high fidelity quantum simulation with $^9Be^+$ ions — •Sebastian Grondkowski[1], Timko Dubielzig[1], Fabian Ude[1], Hening Hahn[2,1], Giorgio Zarantonello[2,1], 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]Physikalisch-Technische-Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig

We describe the necessary experimental infrastructure to perform experiments with an integrated microwave near-field surface-electrode ion trap developed in our group [1] at cryogenic temperatures with applications in quantum simulation and quantum logic. We discuss our loading scheme using a pulsed laser for ablating and a subsequent cw-laser at 235 nm for photo-ionization [2]. An additional laser beam at 313 nm is used for cooling, repumping and detetion of $^9Be^+$ hyperfine qubit ions, similar to [3]. We use a set of water cooled coils which produce a magnetic field of 22.3 mT. At this field the qubit transition becomes field-independent in first order, making the qubit robust against fluctuations. We discuss a sophisticated pulse-shaping scheme to implement quantum logic operations with high fidelity using short microwave pulses (cf. [4]).

[1] M. Carsjens et al., Appl. Phys. B 114, 243-250 (2014)
[2] H.-Y. Lo et al., Appl. Phys. B 114, 17-25 (2014)
[3] A.C. Wilson et al., Appl. Phys. B 105, 741-748 (2011)
[4] D. Hayes et al., PRL 109, 020503 (2012)

Q 40.36 Wed 17:00 P OGs

Simulating boson sampling in free space — •Marc-Oliver Pleinert[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

Boson sampling constitutes a promising model of quantum computation, which probably for the first time will show post-classical calculations, even though it is restricted and non-universal. Here, we investigate a particularly simple boson sampling device consisting of freely propagating photons of different statistics. We relate the boson sampling probabilities to correlation functions in free-space setups. We find that the structure of the multi-photon interferences and spatial correlation functions reflect exactly those occurring in boson sampling and thus are characterized by the permanent of a propagation matrix. As a result, we are able to simulate boson sampling-like computations in free space. We also investigate the computational complexity of such a setup.

Q 40.37 Wed 17:00 P OGs

2D arrays of ion traps in cryogenic environment for quantum information processing — •Philip Holz[1], Kirill Lakhmanskiy[1], Stefan Partel[2], Stephan Kasemann[2], Volha Matylitskaya[2], Johannes Edlinger[2], Muir Kumph[4], Mike Brownnutt[5], Yves Colombe[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Uni Innsbruck, Austria — [2]Fachhochschule Vorarlberg, Dornbirn, Austria — [3]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria — [4]IBM Thomas J. Watson Research Center, Yorktown Heights, USA — [5]The University of Hong Kong, Pokfulam, Hong Kong

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, because of the physical arrangement of the individual trapping sites. We have realized a microfabricated 2D array of individual RF point traps with a 100 micron pitch between trapping sites. The interion distance may be reduced while maintaining a stable trap by varying the RF amplitude on electrodes between two adjacent trapping sites [2]. In this way, coherent operations mediated by the Coulomb interaction should become possible. We report on our progress towards operating the system at cryogenic temperatures and present surface trap designs for a new generation of 2D arrays based on parallel linear traps.

[1] C. Monroe et al., Proceedings of the International School of Physics 'Enrico Fermi', Course 189, pp. 169-187 (2015)
[2] M. Kumph et al., New J. Phys. 18, 023047 (2016)

Q 40.38 Wed 17:00 P OGs

Controlled absorption of a single photon by a single atom via adiabatic transfer — Luigi Giannelli[1], •Tom Schmit[1], Susanne Blum[1,4], Daniel M. Reich[2,3], Christiane P. Koch[2], Tommaso Calarco[5], and Giovanna Morigi[1] — [1]Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Universität Kassel, 34132 Kassel, Germany — [3]Aarhus University, 8000 Aarhus C, Denmark — [4]Theodor-Heuss-Gymnasium, 73730 Esslingen am Neckar, Germany — [5]Universität Ulm, 89069 Ulm, Germany

We analyse the dynamics of a single photon propagating in free space and incident on the mirror of an optical cavity, in which an atom is localized and characterise both numerically as well as analytically the efficiency of protocols which achieve photon absorption by adiabatic transfer [1-3] as a function of dissipative processes and of fluctuations in the experimental parameters. We further characterize the efficiency of the protocols when the signal is an attenuated laser pulse.

[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 40.39 Wed 17:00 P OGs

Characterizing Bell Polytopes for loophole free Bell tests in multipartite scenarios — •Alexander Sauer, Nils Trautmann, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt

Loophole free violations of Bell inequalities are crucial for fundamental tests of quantum nonlocality. They are also important for future applications, such as device-independent quantum cryptography. We estimate the minimal requirements on detectors for performing a loophole free Bell test with dichotomic observables in multipartite scenarios, based on a detector model which includes detector inefficiencies and dark counts. We investigate the structure of Bell polytopes via principal component analysis and take the possible quantum correlations and the no-signaling polytope into account to find suitable Bell inequalities for such tests.

Q 40.40 Wed 17:00 P OGs

Squeezing Distillation from Atmospheric Fluctuations — •Kevin Günthner[1,2], Ömer Bayraktar[1,2], Andreas Thurn[1,2], Christian Peuntinger[1,2], Dominique Elser[1,2], 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.

We show the distillation of squeezed states of light, that have been transmitted through a 1.6 km urban, atmospheric free-space channel [1]. Squeezed states of light are interesting and important non-classical states for quantum information processing [2]. The efficiency of possible applications, e.g., quantum key distribution [3], crucially relies on a state's nonclassicality, i.e., the degree of squeezing. The atmospheric channel introduces intensity fluctuations through beam wandering and scintillation considering the finite receiving aperture size. This real physical, non-gaussian noise will unavoidably lead to reduction of squeezing after transmission. We combat this degrading by employing various purification and distillation protocols, hence selecting states with high degree of squeezing [1,4].

[1] C. Peuntinger *et al.*, Phys. Rev. Lett. **113**, 060502 (2014).
[2] U. L. Andersen *et al.*, Physica Scripta **91**, 053001 (2016).
[3] L. S. Madsen *et al.*, Nature Comm. **3**, 1083 (2012).
[4] J. Heersink *et al.*, Phys. Rev. Lett. **96**, 25 (2006).

Q 40.41 Wed 17:00 P OGs

Construction of a single-NV setup for single-molecule NMR — •Till Lenz[1], Lykourgos Bougas[1], Arne Wickenbrock[1], Samer Afach[1], John W. Blanchard[1], Liam McGuinness[2], Fedor Jelezko[2], and Dmitry Budker[1,3] — [1]Helmholtz Institute, Johannes Gutenberg University, Mainz, Germany — [2]Institut für Quantenoptik, Ulm, Germany — [3]University of California Berkeley, Berkeley, USA

Nuclear magnetic resonance (NMR) spectroscopy plays a central role in modern science, with applications ranging from fundamental physics and chemistry to biomedical imaging. NMR spectroscopy can provide detailed information about the structure and dynamics of molecules, but the realization of measurements with sensitivities at the single-molecule level requires fundamentally new detection strategies. Nitrogen-Vacancy (NV) color centers in diamond have emerged as unique magnetic resonance sensors, marked by the recent remarkable demonstrations of nanoscale spectroscopy and imaging of single electron and nuclear spins. Our goal is to extend the magnetic resonance techniques using NV-centers to Zero- and Ultralow-Field NMR (ZULF-NMR), an alternative technique where measurements are performed in the absence of a strong external magnetic field, which is already used to investigate macroscopic NMR samples. ZULF-NMR allows us to perform single-molecule identification via analysis of J-coupling data.We report on our current efforts in designing, constructing and characterizing a single-NV-based ZULF-NMR spectrometer in Mainz.

Q 40.42 Wed 17:00 P OGs

Properties of the Quantum free-electron laser — •Peter Kling[1,2], Enno Giese[3,2], Roland Sauerbrey[1], and Wolfgang P. Schleich[2,4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, D-01314 Dresden — [2]Universität Ulm, D-89069 Ulm — [3]University of Ottawa, Ottawa, Ontario K1N 6N5, Canada — [4]Texas A & M University, College Station, Texas 77843, USA

In contrast to all existing free-electron lasers (FELs), which purely rely on classical physics, quantum effects are crucial for the 'Quantum FEL' [1]. In this device the discrete recoil of the electron dominates the dynamics, which is characterized by two resonant momentum levels [2,3].

We present intuitive arguments for the transition to the quantum regime and discuss quantities such as gain and photon statistics in this limit. Moreover, we identify effects which distinguish the Quantum FEL from the classical FEL.

[1] R. Bonifacio , N. Piovella and G. R. M. Robb, Fortschr. Phys. **57**, 1041–1051 (2009).
[2] P. Kling *et al.*, New. J. Phys **17**, 123019 (2015).
[3] P. Kling *et al.*, Appl. Phys. B (accepted).

Q 40.43 Wed 17:00 P OGs

Birth, death and revival of spontaneous emission of a three-atom system — Simon Mährlein[1,2], Kevin Günthner[1,3], Jörg Evers[4], and •Joachim von Zanthier[1,2] — [1]Institute of Optics, Information and Photonics, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [3]Quantum Information Processing Group (QIV), Max-Planck-Institut für die Physik des Lichts, 91052 Erlangen, Germany — [4]Theoretical Quantum Dynamics and Quantum Electrodynamics, Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

Death and revival phenomena can be observed in many areas in quantum physics and can appear in different aspects and forms. We investigate the time behavior of spontaneous emission of a three-atom system which collectively shares a single excitation. Two atoms are assumed to be closer than a wavelength to each other, while the third atom is many wavelength away. In a detailed analysis we demonstrate that at certain detector positions the spontaneous emission of the photon can display a birth, i.e., the probability to detect the photon does not decay as a function of time but increases from zero, or a non-periodic death, i.e., the photon detection probability drops to zero, followed by a revival of the signal. We further show that the spontaneous emission process of the fully excited system can be monitored by higher order intensity correlation measurements.

Q 40.44 Wed 17:00 P OGs

Characterisation of open acess microcavities — •Olaf Zimmermann, Andrea Kurz, Felix Glöckler, and Alexander Kubanek — Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany

In order to increase the interaction strength between a single mode of light and the optical transition of an emitter, the emitter can be placed inside the mode of a cavity. To optimize coupling strength either the quality factor can be increased or the mode volume can be decreased. Many cavities that have ultra small mode volumes do not have open access and are not tunable. We present the current status in our development of designing an open accessable, tunable, Fabry-Perot resonator with femtolitre mode volume.

Q 40.45 Wed 17:00 P OGs

Collective sensing at x-ray energies — Paolo Longo, •Dominik Lentrodt, Christoph H. Keitel, and Jörg Evers — MPI für Kernphysik, Heidelberg

We theoretically demonstrate that the cooperative emission from a layer of ^{57}Fe nuclei embedded in an X-ray waveguide can be used as a tool for sensing the presence of external nuclei. The internal nuclei are necessary to counteract the low Q-factor of the cavity. Our approach is based on an evanescent side-coupling mechanism and collective effects from within the waveguide [1] that realise a sufficiently high response for nuclei attached to the waveguide cladding. The results show that a shift of the emission line is only observable if deliberately excited off-resonance. The predicted collective modification of the Lamb shift and linewidth are qualitatively verified using the software package CONUSS.

[1] P. Longo, C. H. Keitel and J. Evers, Sci. Rep. 6, 23628 (2016), arXiv:1503.04532

Q 40.46 Wed 17:00 P OGs

A Lorentz-covariant master equation for a scalar quantum field — •Marduk Bolaños and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

The interaction of quantum particles with their environment has been thoroughly studied in the non-relativistic regime. However, ongoing superposition experiments involving large numbers of photons [1] call for an extension of decoherence models to the electro-magnetic quantum field, which is inherently relativistic. Relativistic models of decoherence will also enable the extension of empirical measures of macroscopicity of the kind introduced in [2] to this regime. As a starting point we consider a relativistic quantum particle, described as an excitation of a scalar field, subject to random momentum kicks. This study will pave the way to a Lorentz-covariant master equation for the dynamics of quantum fields.

[1] E. Nagali et al, PRA 76, 042126 (2007).
[2] S. Nimmrichter and K. Hornberger, PRL 110, 160403 (2013).

Q 40.47 Wed 17:00 P OGs

Thermalization in an isolated quantum system - dynamics and time scales — •Govinda Clos[1], Diego Porras[2], Matthias Wittemer[1], Ulrich Warring[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs-Universität Freiburg, Germany — [2]University of Sussex, Brighton, UK

For an isolated quantum system, the dynamics is governed by the Liouville-von Neumann equation and is, thus, unitary and reversible in time. Yet, few-body observables of (possibly highly-entangled) many-body states can yield expectation values that feature equilibration and thermalization [1]. We use a trapped-ion system to study a spin coupled to a phononic environment of engineerable complexity [2]. While the total system evolves unitarily, we record the dynamics of a subsystem observable, and find the emergence of thermalization. With this time-resolved measurement, we address associated time scales of equilibration, thermalization, and the information flow between the subsystem and its environment.

[1] Eisert *et al.*, Nat. Phys. **11**, 124 (2015).
[2] Clos *et al.*, Phys. Rev. Lett. **117**, 170401 (2016).

Q 40.48 Wed 17:00 P OGs

Asymmetric fiber cavities for quantum opto-mechanics with SiN-membranes — •Jan Petermann[1], Tobias Wagner[1], Philipp Christoph[1], Christoph Becker[1], Klaus Sengstock[1], Hai Zhong[2], Alexander Schwarz[2], and Roland Wiesendanger[2] — [1]Center for Optical Quantum Technologies, Hamburg, Germany — [2]Insitute for Applied Physics, Hamburg, Germany

We are currently setting up a quantum hybrid experiment, which aims at coupling a Bose-Einstein condensate to a cryogenically pre-cooled SiN membrane via long-range light interaction. A fiber cavity is used to enhance the coupling between light and membrane by a factor of the finesse. Asymmetric coating of the cavity mirrors enables finite on-resonance reflectivity required to establish a mutual resonant coupling between the atomic sample and the membrane motion. Our results reveal that the on-resonance reflectivity is extremely sensitive to the mode match between fiber- and cavity mode. Best mode match is achieved for plano-concave cavities. Using standard single mode fibers with mode a field diameter of $5.2\mu m$, we derive an optimal mode match for a radius of curvature close to $50\mu m$ and a cavity length of $L \approx 25\mu m$. We optimize depth and width of our laser machined gaussian mirror profiles by numerical simulations and achieve values for the on-resonance power reflectivity ideally suited for our envisaged quantum hybrid system.

Q 40.49 Wed 17:00 P OGs

A classical linear Boltzmann equation for rotational friction and diffusion — •Lukas Martinetz, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

Motivated by recent experiments [1,2,3], we derive the classical linear Boltzmann equation for the ro-translational dynamics of an arbitrarily shaped anisotropic nanoparticle interacting with a dilute gas. It accounts for specular as well as diffuse thermal reflection of the gas atoms at the particle surface. As a limiting case, the Boltzmann equation describes rotational friction and diffusion. By specifying the form of the nanoobject, we derive the friction and diffusion coefficients for spheres, cylinders and cuboids and discuss the equilibration of the orientation state.

[1] Kuhn et al., Cavity-Assisted Manipulation of Freely Rotating Silicon Nanorods in High Vacuum, Nano Lett. 15, 5604 (2015)

[2] Hoang et al., Torsional Optomechanics of a Levitated Nonspherical Nanoparticle, Phys. Rev. Lett. 117, 123604 (2016)

[3] Kuhn et al., Full Rotational Control of Levitated Silicon Nanorods, arXiv:1608.07315 (2016)

Q 40.50 Wed 17:00 P OGs

Coupling cold atoms to a cryogenically cooled optomechanical device — •Philipp Christoph[1], Jan Petermann[1], Tobias Wagner[1], Christina Staarmann[1], Klaus Sengstock[1,2], Christoph Becker[1,2], Hai Zhong[3], Alexander Schwarz[3], and Roland Wiesendanger[3] — [1]Center for Optical Quantum Technologies, Luruper Chaussee 149 , 22761, Hamburg, Germany — [2]Institute of Laser Physics, Luruper Chaussee 149 , 22761 Hamburg, Germany — [3]Institute for Applied Physics, Jungiusstrasse 11, 20355 Hamburg, Germany

We present work towards a new hybrid quantum system consisting of a sample of cold atoms coupled to a cryogenically precooled mechanical oscillator. Our ultimate goal is the investigation of two very different macroscopically large quantum systems coherently coupled to each other. For this purpose we have set up a Rubidium-BEC apparatus coupled to a SiN membrane placed inside a fiber Fabry Perot cavity via an optical lattice. This membrane in the middle system is cooled to below 500mK in a dilution refrigerator. We present details on the coupling lattice laser system and a highly sensitive homodyne setup for detecting and manipulating the membrane motion. The coupling lattice is operated very close to atomic resonance in order to allow for the required large lattice depth for resonant atom-membrane coupling at low coupling light powers. First results of loading ultracold atoms from a dipole trap into this near resonant lattice are presented.

This work is supported by the DFG grants no. BE 4793/2-1 and SE 717/9-1.

Q 40.51 Wed 17:00 P OGs

Single photon emission from point defects in hexagonal boron nitride flakes — •Bernd Sontheimer[1], Merle Braun[1], Nikola Sadzak[1], Igor Aharonovich[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Belrin — [2]University of Technology Sydney

Single photon emitters play an important role in a variety of quantum technologies, including quantum communications and computing. Here, we introduce Hexagonal boron nitride (hBN), an emerging twodimensional wide-bandgap material, as a host for a multitude of point defects. We investigate those defects and find stable ones at room temperature that show extraordinary bright single photon emission at various wavelengths in the visible and near infrared. Furthermore, present our latest measurements on the temperature dependence of the spectral properties of those defects and show and analyze the apparent spectral diffusion at different time scales as well as optical coherence properties at cryogenic temperatures.

Q 40.52 Wed 17:00 P OGs

Widefield Microwave Imaging using NV Centres — •Andrew Horsley[1], Janik Wolters[1], Patrick Appel[1], James Wood[1], Jocelyn Achard[2], Alexandre Tallaire[2], Patrick Maletinsky[1], and Philipp Treutlein[1] — [1]University of Basel, Switzerland — [2]LSPM, Universite Paris 13, France

We present a microscope for widefield electromagnetic field imaging using NV centres in diamond. We expect to realise $> 1\,\mathrm{mm}^2$ field of view and sub-ms temporal resolution, exceeding the state-of-the-art for widefield NV imaging. The microscope provides $5\,\mu$m spatial resolution, given by the thickness of the near-uniaxial NV layer, and our current sensitivity is hundreds of $\mathrm{nT\,Hz}^{-1/2}$, which we expect to improve.

We use the microscope for microwave near-field imaging, which we are pursuing in the context of microwave device characterisation [2-4]. Such devices form the backbone of many scientific and technological applications, from quantum devices (atom chips, ion traps, atomic clocks, qubits...) to telecommunications (wifi, mobile phones...). Our technique promises to transform device development, characterisation, and debugging. Our high-resolution NV microscope may also be of interest for medical microwave sensing and imaging, particularly in skin-cancer screening.

[1] Steinert et al., Rev. Sci. Instr. 81, 043705 (2010)

[2] Horsley and Treutlein, APL 108, 211102 (2016)

[3] Horsley, Du, and Treutlein, NJP (FTC), 17(11), 112002, (2015)

[4] Appel et al., NJP (FTC), 17(11), 112001, (2015)

Q 40.53 Wed 17:00 P OGs

Low temperature spectroscopy of quantum emitters in 2D materials — •Korbinian Kottmann[1], Andreas Dietrich[1], Stefan Häussler[1], Kerem Bray[2], Igor Aharonovich[2], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Insitute for Quantum Optics, Ulm University, D-89081 Ulm — [2]School Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, New South Wales 2007, Australia

In the previous decade, atomically thin materials have drawn much attention in science and technology because of their extraordinary physical properties due to spatial confinement in two dimensions [1]. We investigate optical properties of individual color centers at very low temperatures (4K). Quantum emission of single photons in the visible spectrum at very high rates make them a promising prospect for applications in quantum communications and photonics. Henceforth, single or few layers can easily be implemented in a micro resonator by virtue of their small size, heralding the possibility of a tunable cavity QED platform.

[1] A. Gupta, T. Sakthivel, S. Seal, Progress in Materials Science 73, 2015

Q 40.54 Wed 17:00 P OGs

Low Temperature spectroscopy of color center in thin diamond layer — •Andreas Dietrich[1], Stefan Häussler[1], Kobinian Kottmann[1], Lukas Antoniuk[1], Kerem Bray[2], 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

Color center in high band gab material, such as diamond, appeared as important and valuable quantum systems for emerging quantum technologies [1]. Engineered diamond materials are demanded for future quantum optics and quantum sensing applications. Preserving optical properties like narrow linewidth and spectral stability in thin membranes is a major task. We investigate in thin diamonds membranes the spectral properties of color centers at low temperature.

[1]F. Jelezko, J. Wrachtrup, Phys. Stat. Sol. 203, 13, 2006

Q 40.55 Wed 17:00 P OGs

Low Temperature spectroscopy of color center in thin diamond layer — •Andreas Dietrich[1], Stefan Häussler[1], Korbinian Kottmann[1], Lukas Antoniuk[1], Kerem Bray[2], 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

Color center in high band gab material, such as diamond, appeared as important and valuable quantum systems for emerging quantum technologies [1]. Engineered diamond materials are demanded for future quantum optics and quantum sensing applications. Preserving optical properties like narrow linewidth and spectral stability in thin membranes is a major task. We investigate in thin diamonds membranes the spectral properties of color centers at low temperature.

[1]F. Jelezko, J. Wrachtrup, Phys. Stat. Sol. 203, 13, 2006

Q 40.56 Wed 17:00 P OGs

Frequency Doubling of Fiber Amplified Picosecond Laserpulses for Ion Beam Cooling — •Christian Kühnel, Daniel Kiefer, and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstr. 7, 64289 Darmstadt

White light cooling is an efficient way for reducing the phase space density of relativistic bunched ion beams [1]. For this purpose we present pulsed SHG in a noncritical phase-matched lithiumniobate crystal. The pulses are provided by a MOPA system with flexible pulse duration.

The MOPA system delivers pulses at 1030 nm and a repetition rate of up to 1.5 MHz. The pulse duration is variable between 70 and 740 ps and switchable to 50 ns. The setup for SHG is typically done for one specific set of laser parameters. However, here it needs to be variable, since the pulse length is tunable. Therefore, the peak power differs so that exceeding damage thresholds and varying SHG efficiencies have to be considered. The current status of the system is presented compared with theoretical and numerical predictions [2]. In addition the future development will be shown. [1] S. N. Atutov. Phys. Rev. Lett. 80 (1998), 2129-2132. [2] H. Wang and A. M. Weiner, IEEE Journal of Quantum Electronics, vol. 39, no. 12, 1600-1618.

Q 40.57 Wed 17:00 P OGs

Tabletop 20 kHz laser source for circularly polarized vacuum ultraviolet radiation — •Tobias Reiker, Daniel Nürenberg, and Helmut Zacharias — Westfälische Wilhelms-Universität, Münster, Deutschland

We present a high repetition rate table top laser source at a photon energy of 10.5 eV with full control over the polarization. The radiation is generated from a 20 kHz Nd:YVO4 laser with a wavelength of 355 nm by frequency tripling in Xenon to a wavelength of 118nm. In this regime, no suitable material for birefringent optics is available. Instead we use a reflection induced phase shift to control the polarization. The Stokes parameter of the radiation are measured by a reflective vacuum ultraviolet polarizer. Circularly polarized light from this source is proposed to be used in spin-resolved photoelectron spectroscopy on surfaces.

Q 40.58 Wed 17:00 P OGs

Stimulated Raman scattering microscopy by Nyquist modulation of a two-branch ultrafast fiber source — •Peter Fimpel, Claudius Riek, Peyman Zirak, Christoph Kölbl, Alfred Leitenstorfer, Daniele Brida, and Andreas Zumbusch — Universität Konstanz

A highly stable setup for stimulated Raman scattering (SRS) microscopy[1] is presented. It is based on a two-branch femtosecond Er:fiber laser operating at a 40 MHz repetition rate. One of the outputs is directly modulated at the Nyquist frequency with an integrated electro-optic modulator (EOM). This compact source combines a jitter-free pulse synchronization with a broad tunability and allows for shot-noise limited SRS detection. The performance of the SRS microscope is illustrated with measurements on samples from material science and cell biology. [1] C. Riek et al., Opt. Lett. 41, 3731 (2016)

Q 40.59 Wed 17:00 P OGs

Atom interferometry with ultracold thermal clouds and realistic laser pulses — •Jens Jenewein, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Universität Ulm, Ulm, Germany

We have developed a real-time simulation for a symmetric and an asymmetric Mach-Zehnder like light-pulse atom interferometer. Realistic laser pulses of arbitrary shape are employed based on single and double Bragg diffraction leading to velocity selectivity and excitation of off-resonant diffraction orders. This feature makes the simulation which also includes lensed thermal atoms more feasible for the description of experiments. We can also estimate the contrast C that contributes together with the atom number to the sensivity. Various effects such as delta-kick collimation and the amount of evaporative cooling affect C.

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 40.60 Wed 17:00 P OGs

Light propagation in a 1D medium of high optical density — •Roman Sulzbach and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstr. 7, 64289, Darmstadt

Electromagnetically induced transparency (EIT) has found many applications in quantum optics, since its experimental demonstration in 1990 [1]. Recently, it was possible to demonstrate EIT and the related effects of slow and stationary light pulses in a hollow fiber containing a thin medium of cold Rubidium atoms [2]. These hollow fibers have a diameter of 7 μm and a length of 10 cm. Therefore, this system represents a one-dimensional medium of high optical density.

We use Maxwell-Bloch theory to simulate the pulse propagation of the probe-beam inside this fiber. This leads to a paraxial Schrödinger-equation as well as to corrections. We will present results of numerical simulations of this strongly interacting light-matter system.

[1] K. Boller, A. Imamoglu, and S. Harris, *Observation of electromagnetically induced transparency*, Phys. Rev. Lett. **66**, 2593 (1991)
[2] F. Blatt, L. Simeonov, T. Halfmann, and T. Peters, *Stationary light pulses and narrowband light storage in a laser-cooled ensemble loaded into a hollow-core fiber*, Phys. Rev. A. **94**, 043833 (2016)

Q 40.61 Wed 17:00 P OGs

From incoherent to coherent: modeling quantum-dot superluminescent diodes — •Franziska Friedrich and Reinhold Walser — Institut für Angewandte Physik

Commercial devices for optical coherence tomography greatly benefit from the appealing features of broadband light emitting quantum-dot superluminescent diodes (QDSLDs), where light is generated in the regime of amplified spontaneous emission (ASE). But also from the fundamental point of view, these devices exhibit uncommon properties considering field and intensity correlations, $g^{(1)}(\tau)$ and $g^{(2)}(\tau)$: a reduction of $g^{(2)}(0)$ from 2 to 1.33 at $T = 190$ K was observed in the lab in 2011 [1]. The understanding of these hybrid coherent light states, which are simultaneously incoherent in $g^{(1)}(\tau)$ and coherent in $g^{(2)}(\tau)$, represents an interesting and challenging topic of research.
In the present contribution, we will discuss a multimode quantized field theory of the QDSLD and study the generation of the amplified spontaneous emission on a microscopic level [2]. As a main result, we analyze the external power spectrum. Comparison with experimental measurements exhibits good agreement.

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

Q 40.62 Wed 17:00 P OGs

Direct probing of higher order Fock states — •Johannes Tiedau, Georg Harder, Vahid Ansari, Tim J. Bartley, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Optical quantum state characterisation is an important task for different scenarios. For many applications, particularly in protocols involving continuous variables, balanced homodyne detection is used to reconstruct a quasi-probability distribution in phase-space to describe the state. However, this method can only investigate the part of the signal field which is overlapping with a strong probe field. In contrast, using a weak local oscillator and photon counting overcomes this problem and enables us to investigate the full quantum state. Depending on the configuration, one can call this weak-field homodyne detection and or direct probing, in which the displaced parity operator of the state is measured. Since there is no intrinsic filtering during measurement, in order to see quantum effects an extremely pure quantum state is required. In our case this is achieved by precise Parametric-Down-Conversion source engineering. We report on our latest progress using this technique, namely direct probing of higher order (>=2) Fock states.

Q 40.63 Wed 17:00 P OGs

Qudi: a modular Python suite for experiment control including implemented modules for confocal microscopy, quantum optics and quantum information experiments — •Jan M. Binder[1], Alexander Stark[1,2], Nikolas Tomek[1], Jochen Scheuer[1], Florian Frank[1], Kay D. Jahnke[1], Christoph Müller[1], Simon Schmitt[1], Mathias H. Metsch[1], Thomas Unden[1], Tobias Gehring[2], Ulrik L. Andersen[2], Lachlan J. Rogers[1], and Fedor Jelezko[1,3] — [1]Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, Ulm 89081, Germany — [2]Department of Physics, Technical University of Denmark, Fysikvej, Kongens Lyngby 2800, Denmark — [3]Center for Integrated Quantum Science and Technology (IQST), Ulm University, 89081 Germany

Qudi is a general, modular, multi-operating system suite written in Python 3 for controlling laboratory experiments.

It provides a structured environment by separating functionality into hardware abstraction, experiment logic and user interface layers.

The core feature set comprises a graphical user interface, live data visualization, distributed execution over networks, rapid prototyping via Jupyter notebooks, configuration management, and data recording.

Currently, the included modules are focused on confocal microscopy, quantum optics and quantum information experiments, but an expansion into other fields is possible and encouraged.

Qudi is available from https://github.com/Ulm-IQO/qudi and is freely useable under the GNU General Public Licence 3.

A preprint describing the design is avaliable at arXiv:1611.09146.

Q 40.64 Wed 17:00 P OGs

Limits on the time-multiplexed photon-counting method — •Regina Kruse, Johannes Tiedau, Tim Bartley, Sonja Barkhofen, and Christine Silberhorn — Applied Physics, Universität Paderborn, Warburger Str. 100, D-33098 Paderborn

Building large and reliable quantum networks requires sophisticated detection techniques to verify the correct operation of the network. To this aim, we investigate the limits of a cost and resource efficient time-multiplexed detection method [1]. We quantify the optimal number of time-bins for such a setup under the constraints of convolution effects and realistic setup losses by simulating the overlap of specified Fock states after passing the time-multiplexed detector.

[1] Kruse et al., arXiv:1611.04360

Q 40.65 Wed 17:00 P OGs

Laserinduzierte Hochspannungsentladung zur Erzeugung eines Plasmawellenleiters für die Elektronenbeschleunigung — •Carola Wirth[1], Alexander Sävert[1,2], Wolfgang Ziegler[1] und Malte C. Kaluza[1,2] — [1]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena — [2]Helmholtz-Institut Jena

Die Erzeugung hochenergetischer Elektronen durch die Laser-Plasmabeschleunigung gewinnt in der Wissenschaft immer mehr an Bedeutung. Bei dieser Art der Beschleunigung werden Elektronen in eine von einem Laserpuls erzeugte Plasmawelle injiziert und können so innerhalb weniger Zentimeter auf Energien von bis zu einigen GeV beschleunigt werden. Um die hohen beschleunigenden Felder der Plasmawelle effektiv nutzen zu können, muss die Welle über eine möglichst lange Strecke bestehen bleiben. Erreicht werden kann dies beispielsweise durch die Führung des treibenden Laserpulses in einem Plasma-Wellenleiter. Ähnlich einer Glasfaser mit einem Gradientenbrechungsindexprofil, in dem Laserstrahlen mit konstantem Strahldurchmesser geführt werden können, kann ein hochintensiver Laserpuls in einem Plasma mit einem transversal parabolischen Brechzahlprofil geführt werden. Eine Technik zur Erzeugung dieses Profils ist die Hochspannungsentladung in einer gasgefüllten Kapillare.

Wir stellen eine Analyse des Stabilitätsverhaltens einer Hochspannungsentladung in einer Kapillare zur Erzeugung eines Plasmakanals vor. Dazu wurde der Einfluss der Vorionisation des Gases mit Hilfe eines intensiven fs-Laserpulses auf das Stabilitätsverhalten und das Führungsverhalten des Plasmakanals untersucht.

Q 40.66 Wed 17:00 P OGs

Three-dimensional Direct Laser Written Waveguides on a Chip — •Alexander Landowski[1,2], Dominik Zepp[1], Sebastian Wingerter[1], Michael Renner[1], Georg von Freymann[1,3], and Artur Widera[1,2] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schroedinger-Str. 56, 67663 Kaiserslautern — [2]Graduate School Materials Science in Mainz, Erwin-Schroedinger-Str. 56, 67663 Kaiserslautern — [3]Fraunhofer-Institute for Physical Measurement Techniques IPM, Fraunhofer-Platz 1, 67663 Kaiserslautern

We engineer three-dimensional waveguides from a low fluorescent photoresist on a chip using a commercial system for direct laser writing. Using a silica substrate and air cladding, we are able to fabricate waveguide bends with small radii down to 40 μm and three-dimensional coupling structures, that enable addressing all input and output ports of our waveguide network through the substrate via one microscope objective simultaneously. Due to the low fluorescence, our waveguides in principle allow integration of single quantum emitters for quantum optical experiments on a chip.

Here we present detailed characterization of stadium waveguides with three-dimensional coupling structures. We discuss the limits of the single mode operation of the waveguides and show first beamsplitting devices. We analyze coupling, propagation and bend losses of our waveguides. Further, we characterize the fluorescence of the photoresist used.

Q 41: Quantum Information: Concepts and Methods VI

Time: Thursday 11:00–13:00 Location: P 2

Group Report Q 41.1 Thu 11:00 P 2

Processing of two matter qubits using cavity QED — •Stephan Welte, Bastian Hacker, Severin Daiss, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

In a quantum network, optical resonators provide an ideal platform for the creation of interactions between matter qubits. This is achieved by 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 [1]. Here we will show how single photons can also be used to generate local entanglement between matter qubits in the same network node [2]. Such entangled states are indispensable as a resource in a plethora of quantum communication protocols. We will give an overview of the necessary experimental toolbox for an implementation with neutral atoms. Several entanglement protocols showing the generation of all the Bell states for two atoms will be presented. We will also detail how we experimentally exploit the employed method for quantum computation and quantum communication applications.

[1] S. Ritter et al., *Nature* **484**, 195 (2012)
[2] A. Sørensen and K. Mølmer, *Phys. Rev. Lett.* **90**, 127903 (2003)

Q 41.2 Thu 11:30 P 2

Robust creation of large entangled quantum states in Rydberg lattice system — •Maike Ostmann[1,2], Jiri Minar[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, Nottingham, NG7 2RD, United Kingdom

Due to new experimental developments, the generation of quantum states in Rydberg lattice systems is of interest. Recently, there has been success in the realisation of a quantum simulator for an Ising model using Rydberg atoms [1]. This promising new platform is able to deal with one and two-dimensional arrays of arbitrary geometry. Furthermore, new procedures to prepare neutral atoms in optical lattices with unit filling fraction have been developed [2,3]. Consequently, the question arises whether it is possible to easily produce a quantum state, which can be used as a resource state in quantum simulators or quantum computation. A simple protocol, which makes use of the Rydberg blockade effect, is considered. Three laser pulses are applied to a one-dimensional chain of Rydberg atoms resulting in an entangled graph state. The effect of this protocol has been simulated, and the entanglement of the state is specified by calculating the concurrence depending on the interatomic separation. [1] H. Labuhn et al., arXiv:1509.04543 (2016) [2] D. Barredo et al., arXiv:1607.03042 (2016) [3] M. Endres et al., arXiv:1607.03044 (2016)

Q 41.3 Thu 11:45 P 2

Randomized entanglement detection — •Jasmin D. A. Meinecke[1,4,5], Lukas Knips[1,4], Jan Dziewior[1,4], Pete Shadbolt[2], Joseph Bowles[3], Nicolas Brunner[3], Jeremy O'Brien[5], and Harald Weinfurter[1,4] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — [2]Department of Physics, Imperial College London, SW7 2AZ, UK — [3]Groupe de Physique Appliquée, Université de Genève, CH-1211 Genève, Switzerland — [4]Fakultät für Physik, Ludwig-Maximilians-Universität München, D-80799 München, Germany — [5]Centre for Quantum Photonics, H. H. Wills Physics Laboratory & Department of Electrical and Electronic Engineering, University of Bristol, Merchant Venturers Building, Woodland Road, Bristol, BS8 1UB, UK

Entangled particles exhibit quantum correlations over arbitrary long distances in time and space which cannot be mimicked by local realistic models. In order to detect and utilize these correlations for quantum information tasks, measurements in different bases are necessary. Schemes for experimentally characterizing quantum states have been devised, which are often experimentally demanding in terms of stability and insensitivity against noise. We show that entanglement detection is possible even under uncontrolled, unknown, local environmental noise on the quantum channel - a scenario under which established entanglement witnesses and tomography schemes fail - and demonstrate our new practical method by determining the degree of entanglement and purity of an unknown state using photonic multi-qubit states.

Q 41.4 Thu 12:00 P 2

Measurement-device-independent randomness generation with arbitrary quantum states — •Felix Bischof, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

Measurements of quantum systems can be used to generate classical data that is truly unpredictable for every observer. However, this true randomness needs to be discriminated from randomness due to ignorance or lack of control of the devices. At the same time, the number of assumptions and explicit modeling of the devices should be low to guarantee the safety and practicality of the scheme.

We analyze the randomness gain of a measurement-device-independent setup, consisting of a well-characterized source and completely uncharacterized detector. Our framework generalizes previous schemes[1] as it quantifies the randomness generation for any implementation: arbitrary input states, and detectors with an arbitrary number of outcomes can be analyzed. Our method is used to suggest simple and realistic implementations that yield high randomness generation rates of more than one random bit per qubit for detectors of sufficient quality.

[1] Z. Cao, H. Zhou, and X. Ma (2015)

Q 41.5 Thu 12:15 P 2

Free-Space Entangled Quantum Carpets — •Andreas Ketterer[1,2], Mariana R. Barros[3], Osvaldo J. Farías[4], Fernando de Melo[4], and Stephen P. Walborn[3] — [1]Université Paris Diderot, Paris, France — [2]Universität Siegen, Siegen, Germany — [3]Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil — [4]Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil

The Talbot effect in quantum physics is known to produce intricate patterns in the probability distribution of a particle, known as "quantum carpets", corresponding to the revival and replication of the initial wave function. Recently, it was shown that one can encode a D-level qudit, in such a way that the Talbot effect can be used to process the D-dimensional quantum information [1]. In this talk I will introduce a scheme to produce free-propagating "entangled quantum carpets" with pairs of photons produced by spontaneous parametric down-conversion [2]. First I introduce an optical device that can be used to synthesize arbitrary superposition states of Talbot qudits. Sending spatially entangled photon pairs through a pair of these devices produces an entangled pair of qudits. As an application, I show how the Talbot effect can be used to test a D-dimensional Bell inequality.

[1] O. J. Farías et al., Phys. Rev. A **91**, 062328 (2015)
[2] M. R. Barros, A. Ketterer et al., *in prep.* (2016)

Q 41.6 Thu 12:30 P 2

Recovering quantum properties of continuous-variable states in the presence of measurement errors — •Evgeny Shchukin and Peter van Loock — Johannes-Gutenberg University of Mainz, Institute of Physics, Staudingerweg 7, 55128 Mainz, Germany

We present two results which combined enable one to reliably detect multimode, multipartite entanglement in the presence of measurement errors. The first result leads to a method to compute the best (approximated) physical covariance matrix given a measured non-physical one assuming that no additional information about the measurement is available except the standard deviations from the mean values. The other result states that a widely used entanglement condition is a consequence of negativity of partial transposition. Our approach can quickly verify entanglement of experimentally obtained multipartite states, which is demonstrated on several realistic examples. Compared to existing detection schemes, ours is very simple and efficient. In particular, it does not require any complicated optimizations.

Q 41.7 Thu 12:45 P 2

Distribution of entanglement in arbitrary finite dimensionality — •Christopher Eltschka[1] and Jens Siewert[2,3] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Departamento de Química Física, Universidad del País Vasco UPV/EHU, E-48080 Bilbao, Spain — [3]IKERBASQUE Basque Foundation for Science, E-48013 Bilbao, Spain

While the quantitative theory of bipartite entanglement is developed quite far, much less is known regarding multipartite entanglement. Moreover, many of the results on multipartite entanglement are specific to qubit systems. An important example that illustrates this point is the distribution of entanglement (as well as other quantum correlations), often termed as 'monogamy of entanglement'. Here, essentially all of the quantitative results are established only for qubits, although the concept is believed to be valid in general.

In this contribution we present exact results for an arbitrary number of parties of arbitrary finite Hilbert space dimensions. It turns out that, by generalizing the multi-qubit case, a new concurrence-like entanglement monotone can be introduced. We show that this monotone is closely related to the distribution of bipartite entanglement across the multi-party system.

Q 42: Quantum Effects

Time: Thursday 11:00–13:00 Location: P 4

Q 42.1 Thu 11:00 P 4

Probing the measurement process in DTQW via recurrence — •Thomas Nitsche[1], Regina Kruse[1], Linda Sansoni[1], Martin Štefaňák[2], Tamás Kiss[3], Igor Jex[2], Sonja Barkhofen[1], and Christine Silberhorn[1] — [1]Applied Physics, University of Paderborn, Germany — [2]Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Czech Republic — [3]Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Hungarian Academy of Sciences, Hungary

The measurement process plays a crucial role in quantum mechanics as it interrupts the unitary evolution of a state. The consequences are apparent when investigating the return probability (Polya-number) of a particle in a Hadamard walk on the line [1, 2]: Depending on whether the evolution is restarted or continued after the measurement, either a transient or a recurrent evolution can be observed. We investigate both cases experimentally for the first time by introducing sinks in a time-multiplexed quantum walk setup using a fast-switching electro-optic modulator (EOM). Monitoring the evolution of the walker over 39 steps reveals the fundamental differences of the two cases as predicted by theory: In the restart-regime, the Polya-number will gradually approach unity. In contrast, the continue-regime yields an asymptotic value of the Polya-number of $2/\pi$, which is reached in good approximation after only four steps and then remains almost constant.

[1] M. Štefaňák, I. Jex, and T. Kiss, PhysRevLett **100**, 020501 (2008)
[2] F. A. Grünbaum, L. Velázquez, A. H. Werner, and R. F. Werner, Commun. Math. Phys. **320**, 543 (2013)

Q 42.2 Thu 11:15 P 4

A light-atom interface based on a high numerical aperture lens — •Matthias Steiner[1,2], Yue-Sum Chin[1], and Christian Kurtsiefer[1,2] — [1]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543 — [2]Department of Physics, National University of Singapore, 2 Science Drive 3, Singapore 117542

Quantum interfaces between atoms and photons require engineering of the coupling. Usually, this is accomplished with optical resonators. Tightly focused free-space modes are a complementary tool for interaction engineering.

We present a light-atom interface consisting of a single Rubidium atom trapped at the focus of a high numerical aperture lens, NA=0.75. A coherent light beam probes the near-resonant interaction with the atom and we characterize the coupling strength by a reflection and a transmission measurement. We investigate the temperature dependence of the interaction in order to understand whether the residual positional spread of the atom limits the interaction strength. The resonance frequency shifts and interaction strength with the external field decreases when the atom is heated by the recoil of the scattered photons. Comparing to a simple model, we conclude that the initial temperature reduces the interaction strength by less than 10% [1].

[1] Y.-S. Chin, M. Steiner, C. Kurtsiefer, arXiv:1611.08048

Q 42.3 Thu 11:30 P 4

Genuine Quantum Signatures in Synchronization of Anharmonic Self-Oscillators — Niels Loerch[1], •Ehud Amitai[1], Andreas Nunnenkamp[2], and Christoph Bruder[1] — [1]Department of Physics, University of Basel, Basel, Switzerland — [2]Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom

We study the synchronization of a Van der Pol self-oscillator with Kerr anharmonicity to an external drive. We demonstrate that the anharmonic, discrete energy spectrum of the quantum oscillator leads to multiple resonances in both phase locking and frequency entrainment not present in the corresponding classical system. Strong driving close to these resonances leads to nonclassical steady-state Wigner distributions. Experimental realizations of these genuine quantum signatures can be implemented with trapped ions or optomechanical systems.

Q 42.4 Thu 11:45 P 4

Non-Markovianity and the physics of memory — •Nina Megier[1], Dariusz Chruściński[2], Jyrki Piilo[3], and Walter T. Strunz[1] — [1]TU Dresden — [2]Nicolaus Copernicus University in Toruń — [3]University of Turku

In our work we analyse a family of qubit CPT maps, characterized by a point within a parameter triangle. The corresponding generator of the dynamics may contain exactly one negative decoherence rate. Based on the concept of CP-divisibility such evolution is classified as non-Markovian. Nonetheless, the dynamical map can be written as a random unitary evolution or a convex combination of Markovian semigroups. Remarkably, we find a realisation based on a classical Markov process, where the probabilities are governed by a classical Pauli master equation. Such a classical Markov representation exists also for a non-P-divisible dynamics of an extended two qubit system. In both cases a description with a bipartite GKSL equation, where the ancilla state is frozen, is possible, too. These realisations show that actually there is no room for physical memory effects. Therefore, both non-CP-divisibility, but also the weaker non-P-divisibility, are sometimes questionable indicators for non-Markovianity. A reduced description may not suffice to study the physics of memory and information flow.

Q 42.5 Thu 12:00 P 4

Dopplerfreie drei-Photonen Kohärenz in Quecksilberdampf — •Benjamin Rein, Jochen Schmitt und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Lasing without inversion (LWI) ist eine auf kohärenter Anregung basierende Technik, die es prinzipiell ermöglicht, Laserstrahlung bis in den tiefen VUV-Bereich zu erzeugen. Bisherige LWI-Experimente wurden in atomaren drei-Niveau Systemen durchgeführt, in denen der LWI-Effekt durch die Dopplerverbreiterung im Medium „auswischt", wenn der Wellenlängenunterschied zwischen Kopplungslaser und LWI-Laserübergang mehr als einige Nanometer beträgt.

Quecksilber bietet ein vier-Niveau System, in dem es möglich ist, die Dopplerverbreiterung durch eine geschickte geometrische Anordnung der Laserstrahlen zu kompensieren und somit das Potential bietet, erstmals LWI im UV-Bereich bei 253,7 nm zu realisieren. Die kohärente Anregung erfolgt bei Wellenlängen von 435,8 nm und 546,1 nm.

Es werden Messungen der dopplerfreien drei-Photonen Resonanz vorgestellt, sowie erste Messungen in einer *amplification without inversion* Konfiguration. Ein detailliertes theoretisches Modell zeigt, dass das Gesamtsystem das Potential für erste LWI-Messungen im UV-Bereich besitzt.

Q 42.6 Thu 12:15 P 4

Intrinsic quantum chaos in the complex atomic system of protactinium — •Pascal Naubereit[1], Victor Flambaum[2,3], Dominik Studer[1], Anna Viatkina[2], and Klaus Wendt[1] — [1]Institute of Physics, Johannes Gutenberg University, 55128 Mainz, Germany — [2]Helmholtz Institute Mainz, 55128 Mainz, Germany — [3]School of Physics, University of New South Wales, Sydney 2052, Australia

Quantum chaos, initially experienced in scattering resonances of nuclei, today is a widely discussed phenomenon observed in various complex quantum systems. In this talk we discuss the occurrence and experimental investigation of intrinsic quantum chaos within the highly complex atomic system of protactinium, as expressed in the arrangement of levels. The resulting repulsion of individual states can be traced back to chaotic mixing of a very large number of single electron states, which arise from the five easily excitable electrons within up to four different open valence shells. In order to analyze a reasonable fraction of energy levels of given parity and angular momentum, the highly complex spectrum of the protactinium atom was probed experimentally in different ranges of excitation energy by using multi-step laser resonance ionization spectroscopy. Together with the available literature data we can reproduce a complete overview of excited states of the protactinium atom from ground state up to energies above the first ionization potential. By investigation of the most pronounced indicator, the repulsion of states, we derive how intrinsic quantum chaos in this system evolves with energy and emphasize its significance already at moderate excitation energy.

Q 42.7 Thu 12:30 P 4

Localization and Multifractality in Disordered Long-Range Hopping Models — •Xiaolong Deng[1], Vladimir Kravtsov[2], Georgy Shlyapnikov[3], and Luis Santos[1] — [1]ITP, Leibniz Universität Hannover, Germany — [2]ICTP, Trieste, Italy — [3]LPTMS, Orsay, France

We study disordered single-particle lattice model with long-range hops. We prove that all of eigenstates are localized in one- and two-dimensional isotropic systems. In three dimensional systems we show the mobility edge separating delocalized and localized states.

Q 42.8 Thu 12:45 P 4

Nuclear motion is classical — •Irmgard Frank — Theoretische Chemie, Universität Hannover

The Born-Oppenheimer approximation suffers from strong and not fully understood drawbacks. One might believe, that ninety years after its invention one could omit it and compute ionic and electronic motion together having big computers. However, as the Schrödinger equation has similarities with the diffusion equation, the resulting nuclear wavefunction diffuses. The resulting potential for the electrons allows them to further diffuse again, etc., the result being a homogeneous gas of electrons and nuclei. We show that this can be avoided in a very simple way by describing the nuclei right from the beginning as classical point particles which obey the Newton equations. This approximation works well for the region of normal energies and is superior to a quantum chemical description of the nuclei.

Q 43: Laser Applications: Optical Measurement Technology

Time: Thursday 11:00–12:15 Location: P 5

Group Report Q 43.1 Thu 11:00 P 5

Novel optical beams, from accelerating wavepackets to Janus waves — •Dimitrios Papazoglou[1,2] and Stelios Tzortzakis[1,2,3] — [1]Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas, P.O. Box 1527, 71110, Heraklion, Greece — [2]Department of Material Science and Technology, University of Crete, P.O. Box 2208, 71003, Heraklion, Greece — [3]Science Program, Texas A&M University at Qatar, P.O. Box 23874, Doha, Qatar

Lately a plethora of optical beams with non-trivial amplitude and phase distributions like for example the accelerating Airy and ring-Airy beams have been introduced. These novel optical beams propagate in curved trajectories and resist to diffraction or dispersion. Therefore, they are able to self-heal and bypass obstacles, advantages that make them exiting for applications ranging from materials processing to telecommunications. Recently we have revealed that these waves are members of the broader family of Janus waves. Counterintuitively, when these Janus waves are focused, two focal regions, instead of one are formed. On the other hand, the generation and control of these wavepackets is not trivial. Their complexity challenges our current state of the art techniques for wavefront shaping, and has urged us to exploit, among others, unconventional approaches like the use of optical aberrations. The talk will focus on the exciting ongoing quest of materializing these novel optical wavepackets, and their usage to a broad range of applications ranging from tailored filaments, light bullets, multi-photon polymerization and THz generation.

Q 43.2 Thu 11:30 P 5

"Single Pixel" Imaging and its application in beam profile analysis — •Daniel Laukhardt, Till Mohr, Sébastien Blumenstein, and Wolfgang Elsässer — Technische Universität Darmstadt, Darmstadt, Germany

Nowadays it is not implicitly necessary to make use of high resolution cameras in order to get spatial resolved images. With the progress of computational capacity the application of single pixel detectors appeared more frequently in the scope of imaging. To achieve spatial resolution in this single pixel detector concept, a set of particular masks is needed which is sequentially projected onto the object, providing the spatial information. This task can be fulfilled by digital micromirror devices (DMD) which have the advantage of a high reflectivity in a broad wavelength range. Recent applications of single pixel imaging range from real time 3D imaging in the visible spectrum [1] to imaging in the terahertz spectral region [2].

In this contribution, we perform beam profile analysis using the single pixel imaging concept for a large wavelength span using a DMD and three different single pixel detectors. Thereby we are able to measure the beam profile of different light sources covering the range from the blue visible to the mid infrared spectral region.

[1] B. Sun et al., Science, Vol. 340, Issue 6134, pp. 844-847 (2013)
[2] W. L. Chan et al., Appl. Phys. Lett., Vol. 93, 121105 (2008)

Q 43.3 Thu 11:45 P 5

Miniature cavity-enhanced diamond magnetometer — •Georgios Chatzidrosos[1], Arne Wickenbrock[1], Lykourgos Bougas[1], Nathan Leefer[2], Teng Wu[1], Kasper Jensen[3], Yannick Dumeige[4], and Dmitry Budker[1,2,5,6] — [1]Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany — [2]Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen, Denmark — [3]CNRS, UMR 6082 FOTON, Enssat, 6 rue de Kerampont, CS 80518, 22305 Lannion cedex, France — [4]Helmholtz Institut Mainz, 55099 Mainz, Germany — [5]Department of Physics, University of California, Berkeley, CA 94720-7300, USA — [6]Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

We present a miniaturized cavity-enhanced room-temperature magnetic field sensor based on nitrogen vacancy (NV) centers in diamond. The magnetic resonance signal is detected by probing absorption on the 1042 nm spin-singlet transition. The enhanced absorption of the infrared light gives an improved signal contrast greater than 13% at room temperature. Based on this, we demonstrate a magnetic-field sensitivity of $120\,\mathrm{pT}/\sqrt{\mathrm{Hz}}$, and a projected a photon shot-noise-limited sensitivity of $12\,\mathrm{pT}/\sqrt{\mathrm{Hz}}$ for the amount of infrared light collected, while the quantum projection-noise-limited sensitivity for our sensing volume of $\sim 390\mu\mathrm{m} \times 1200\ \mu\mathrm{m}^2$ is estimated to be $0.7\,\mathrm{pT}/\sqrt{\mathrm{Hz}}$

Q 43.4 Thu 12:00 P 5

Microwave-free magnetometry with nitrogen-vacancy centers in diamond — •Huijie Zheng[1,2], Arne Wickenbrock[1,2], Lykourgos Bougas[1,2], Nathan Leefer[1,2], Samer Afach[2], Andrey Jarmola[3], Victor. M Acosta[4], and Dmitry Budker[1,2,3,5] — [1]Johannes Gutenberg-Universitaet Mainz, 55128 Mainz, Germany — [2]Helmholtz Institut Mainz, 55128 Mainz, Germany — [3]University of California, Berkeley, CA 94720-7300, USA — [4]University of New Mexico, Center for High Technology Materials, Albuquerque, NM 87106, USA — [5]Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

We demonstrate a method of all-optical magnetometry by using magnetic-field-dependent features in the photoluminescence of negatively charged nitrogen-vacancy centers. In particular, our method relies on the level anti-crossing (LAC) in the triplet ground state at 102.4mT without the requirement of microwaves. Firstly, we present a magnetometer with a demonstrated noise floor of $6\,\mathrm{nT}/\sqrt{\mathrm{Hz}}$. Secondly, we show how the sensitivity is improved by implementing a more dilute diamond sample with a smaller linewidth of the LAC feature in a more homogeneous background field. The technique presented here removes the microwave requirements for magnetometry with NV centers which makes the scheme potentially useful in applications where the sensor is placed close to conductive materials.

Q 44: Photonics II

Time: Thursday 11:00–13:00 Location: P 11

Q 44.1 Thu 11:00 P 11

Amorphous silicon-doped titania films for on-chip photonics — •Thomas Kornher[1], Kangwei Xia[1], Roman Kolesov[1], Stefan Lasse[1], Cosmin S. Sandu[2], Estelle Wagner[2], Scott Harada[2], Giacomo Benvenutti[2], Bruno Villa[4], Hans-Werner Becker[3], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Germany — [2]3D-OXIDES, Saint Genis Pouilly, France — [3]RUBION, Ruhr-Universität Bochum, Germany — [4]Semiconductor Physics Group, Cambridge, UK

High quality optical thin film materials form a basis for on-chip photonic micro- and nano-devices, where several photonic elements form an optical circuit. Their realization generally requires the thin film to have a higher refractive index than the substrate material. Here, we demonstrate a method of depositing amorphous 25% Si doped TiO_2 films on various substrates, a way of shaping these films into photonic elements, such as optical waveguides and resonators, and finally, the performance of these elements. The quality of the film is estimated by measuring thin film cavity Q-factors in excess of 10^5 at a wavelength of 790 nm, corresponding to low propagation losses of 5.1 db/cm. The fabricated photonic structures were used to optically address chromium ions embedded in the substrate by evanescent coupling, therefore enabling it through film-substrate interaction. Additional functionalization of the films by doping with optically active rare-earth ions such as erbium is also demonstrated. Thus, $Si{:}TiO_2$ films allow for creation of high quality photonic elements, both passive and active and provide access to a broad range of substrates and emitters embedded therein.

Q 44.2 Thu 11:15 P 11

Towards integrating superconducting detectors on lithium niobate waveguides — •Jan Philipp Höpker[1], Evan Meyer-Scott[1], Moritz Bartnick[1], Frederik Thiele[1], Nicola Montaut[1], Harald Hermann[1], Sebastian Lengeling[1], Raimund Ricken[1], Viktor Quiring[1], Stephan Krapick[1], Matteo Santandrea[1], Adriana Lita[2], Varun Verma[2], Thomas Gerrits[2], Sae Woo Nam[2], Christine Silberhorn[1], and Tim J. 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

Depositing superconducting detectors onto optical waveguides is a promising way to achieve precise single photon detection in integrated optical circuits. We have taken the initial steps in depositing transition edge sensors (TES) and superconducting nanowire single photon detectors (SNSPDs) on titanium in-diffused lithium niobate waveguides. At room temperature, the excess transmission loss is measured with a Fabry-Pérot etalon technique, which gives information about the detector absorption of the deposited TES and SNSPDs without wiring them. Furthermore, simulations are carried out to optimize the detector structures and include additional dielectric layers for better absorption efficiencies. To test the devices at cryogenic temperatures, the coupling to optical fibres via end-face pigtailing is investigated, using a precise motorized stage and UV-glue. Together with our pigtailing technique and the superconducting detectors we expect to be able to make a functional integrated single photon detection device.

Q 44.3 Thu 11:30 P 11

Optimisation of luminescence in multi-layered photonic structures to increase the efficiency of upconversion processes — •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, in combination with photonic structures, open promising possibilities to improve the efficiency of silicon solar cells by utilising the full range of the solar spectrum [1].

By tuning the thickness of each individual layer in a multi-layered photonic structure, we show that it is possible to trap incident photons of a given wavelenght inside this structure, and thus considerably increase the local irradiance in those layers which contain the upconverter material. We compare the achievable enhancement of the local irradiance, as well as its robustness under manufactoring errors, as obtained for the resulting optimal geometries to thus far experimentally implemented [1] Bragg structures.

[1] C. L. M. Hofmann, B. Herter, S. Fischer, J. Gutmann, and J. C. Goldschmidt, „Upconversion in a Bragg structure: photonic effects of a modified local density of states and irradiance on luminescence and upconversion quantum yield“, Opt. Express 24, 14895-14914 (2016)

Q 44.4 Thu 11:45 P 11

Diffraction-limited imaging with 3D printed complex mesoscale objectives — •Simon Ristok[1], Simon Thiele[2], Timo Gissibl[3], Alois Herkommer[2], and Harald Giessen[1] — [1]Universität Stuttgart, 4. Physikalisches Institut — [2]Universität Stuttgart, Institut für technische Optik — [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. The achievable size ranges from a few micrometers up to several millimeters. Apart from simple spherical lenses, optical systems with multiple lenses, such as doublet or triplet objectives can be printed.

In this work we focus on objectives with diameters of several 100 micrometers. They show excellent imaging properties, with optical resolution close to the diffraction limit, even for large fields of view. Furthermore, we are able to print our microoptics directly on various surface materials, e.g. CMOS sensors or optical fibers, opening up a wide range of possible applications.

Q 44.5 Thu 12:00 P 11

Photon-statistics-based ghost imaging with one single detector — •Lydia Fischer, Simone Kuhn, Sébastien Blumenstein, and Wolfgang Elsässer — Institute of Applied Physics, TU Darmstadt, Germany

Ghost Imaging is an imaging technique in which intensity correlations of light are exploited. A light beam is directed onto an object and the entirely transmitted or reflected light is collected by a single pixel detector. By the correlation of this beam with a second, spatially resolved, highly correlated reference beam which does not interact with the object, an image can be formed.
Here we demonstrate a novel ghost imaging scheme. Instead of the two detector concept, the light from the object and reference beam is superimposed and then detected by one single photon counting detector. The combination of a fast single photon avalanche diode (SPAD) and a time tagged time resolved (TTTR) photon counting module allows acquiring photon count time traces. The statistical evaluation of these time traces yields the combined photon number probability distribution. Thereby one can compute all moments of the photon distribution and thus the correlation coefficients. In combination with the spatial information of the reference arm a ghost image can be formed. By presenting a proof-of-principle ghost imaging experiments in one and two dimensions, the feasibility of the photon statistics based GI experiment is demonstrated.
[1] S.Kuhn, S.Hartmann, and W. Elsäßer, Opt.Lett.41, 2863-2866 (2016)

Q 44.6 Thu 12:15 P 11

Automated aberration compensation in high numerical aperture systems for arbitrary laser modes — •Julian Hering[1], Erik H. Waller[1], and Georg von Freymann[1,2] — [1]Physics department and state research center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Fraunhofer Institute for Physical Measurement Techniques (IPM), 67663 Kaiserslautern, Germany

In three-dimensional laser lithography, controlling the point-spread-function (PSF) is crucial for fabricating structures with highest resolution and minimal feature sizes. Aberrations present within most optical systems have to be physically compensated prior to the writing process.

Here, we report on a modified Gerchberg-Saxton algorithm (GSA) for spatial-light-modulator (SLM) based automated aberration compensation for arbitrary laser modes like, e.g., doughnut, bottlebeam, and multi-foci modes in a high numerical aperture system. First-guess initial amplitude and phase conditions of the pupil function and circularly polarized light allow for a non-vectorial phase retrieval of the distorted PSF and thus, its shape optimization. Our approach outperforms recent algorithms considering vectorial corrections.

Besides direct laser writing also applications like stimulated emission depletion based microscopy or optical tweezer arrays might benefit from the presented method.

Q 44.7 Thu 12:30 P 11

Attosecond scale coherent control of electron recombination in the polarization plane — •Ofer Kfir[1,2], Sergey Zayko[1], Christina Nolte[3], Stefan Mathias[3], Oren Cohen[2], and Claus Ropers[1] — [1]IV. Physical Institute, University of Göttingen, Göttingen, Germany — [2]Solid State Institute and Physics Department, Technion, Haifa, Israel — [3]I. Physical Institute, University of Göttingen, Göttingen, Germany

The strong-field ionization of atoms and molecules in intense optical laser fields leads to a sequence of coherent recollisions of electrons with their parent ion, with attosecond timing information imprinted onto the emitted high-order harmonic radiation [1].

Here, we use a bi-chromatic field characterized by two orthogonal Jones vectors [2,3] that precisely control the phase, timing and orientation of attosecond recollisions in the two-dimensional polarization plane, under conditions that maintain a high recollision probability. Besides the generation of circularly polarized harmonics [2], we demonstrate the selective suppression or enhancement of different classes of harmonic orders by tuning the interference conditions of three subsequent attosecond recollisions. For example, we convert the typically suppressed harmonics in bi-circular fields to be bright and circularly polarized. This new control scheme provides attosecond access to the study of various two-dimensional phenomena in molecules, including sub-cycle charge redistribution.

[1] Shafir, Nature 485, 343 (2012). [2] Fleischer, Nat. Phot. 8, 543 (2014). [3] Milošević PRA 62, 11403 (2000).

Q 44.8 Thu 12:45 P 11

Effective Medium Theory for infinitely-long polaritonic cylinders — •Charalampos P. Mavidis[1,2], Maria Kafesaki[1,2], Eleftherios N. Economou[1,3], and Costas M. Soukoulis[1,4] — [1]Institute of Electronic Structure and Laser, FORTH, 71110 Heraklion, Crete, Greece — [2]Department of Materials Science and Technology, University of Crete, Heraklion, Crete, Greece — [3]Department of Physics, University of Crete, Heraklion, Greece — [4]Ames Laboratory and Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA

In this work we present an effective medium theory for infinitely-long cylinders in a host medium. Based on the scattering by a single cylinder we derive analytic expressions for all components of the effective electric permittivity and effective magnetic permeability tensors cylinder beyond the Maxwell-Garnett approximation of a system.

The derived equations are applied to systems of cylinders made of polaritonic materials (e.g. LiF, SiC, etc) immersed in dielectric materials in the THz part of the spectrum. Using different combinations of materials and radii many interesting phenomena arise, including hyperbolic dispersion relation, negative refractive index and Near-Zero index media. Finally, we test the results with full-wave numerical calculations using a Finite Element-based solver.

Q 45: Ultracold Plasmas, Rydberg Systems and Molecules

Time: Thursday 11:00–13:15 Location: P 104

Group Report Q 45.1 Thu 11:00 P 104

Coherent excitation of a single trapped Rydberg ion — •Fabian Pokorny[1], Gerard Higgins[1,2], Chi Zhang[1], Quentin Bodart[1], and Markus Hennrich[1] — [1]Department of Physics, Stockholm University, 10691 Stockholm, Sweden — [2]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria

Trapped Rydberg ions are a novel approach for quantum information processing [1]. By combining the high degree of control of trapped ion systems with the long-range dipolar interactions of Rydberg ions [2], fast entanglement gates may be realised in large ion crystals [3].

Quantum information processing in such a system links qubit rotations in the ions' ground states with entanglement operations via the Rydberg interaction. This combination of quantum operations requires that the Rydberg excitation can be controlled coherently.

In the experiments presented here a strontium ion confined in a linear Paul trap was excited to the Rydberg state via a two-photon excitation with 243nm and 307nm light [4]. We observed EIT in this system and mapped the population to the Rydberg state and back via STIRAP. This is the first observed coherently manipulated Rydberg excitation of an ion.

[1] M. Müller, et al., New J. Phys. **10**, 093009 (2008)
[2] D. Jaksch, et al., Phys. Rev. Lett. **85**, 2208 (2000)
[3] F. Schmidt-Kaler, et al, New J. Phys. **13**, 075014, (2011)
[4] G. Higgins, et al, arXiv:1611.02184v1, (2016)

Q 45.2 Thu 11:30 P 104

Multicritical behavior in dissipative Ising models — •Vincent Overbeck[1], Mohammad Maghrebi[2], Alexey Gorshkov[2], and Hendrik Weimer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Joint Quantum Institute and Joint Center for Quantum Information and Computer Science, NIST/University of Maryland, College Park, Maryland 20742, USA

Physical phenomena of dissipative quantum many-body systems can be quite different from those of their equilibrium counterparts. We analyze a Z_2- preserving dissipative Ising model using a variational principle [1,2]. In the steady state phase diagram, we find in addition to a continuous transition, a first order transition between an ordered and an unordered phase and a tricritical point. We extend our analysis by a Ginzburg-Landau approach, verifying in detail the validity of our product state ansatz. We show that fluctuations due to spatial inhomogeneities are produced in the same way as in equilibrium, allowing us to determine an upper critical dimension, above which fluctuations in the multicritical regime vanish and the critical exponents of our product state theory become correct. Finally, we will present a renormalization group analysis of our functional, investigating how a one loop correction influences the position of the tricritical point.

[1] H. Weimer, Variational Principle for Steady States of Dissipative Quantum Many-Body Systems, Phys. Rev. Lett. 114, 040402 (2015).
[2] H. Weimer, Variational analysis of driven-dissipative Rydberg gases, Phys. Rev. A 91, 063401 (2015).

Q 45.3 Thu 11:45 P 104

Critical properties of a one-dimensional adsorbing state model — •Maryam Roghani and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We study a quantum version of a one-dimensional adsorbing state model [1]. We find evidence for a steady state phase transition between a phase with algebraic correlations (active) and a phase with exponential decay (inactive). Remarkly, this transition appears to be present despite the system being in a mixed state. In the active phase, we also look into the quantum mutual information of the steady state, comparing to scaling predictions from conformal field theory.

[1]. M. Marcuzzi, M. Buchhold, S. Diehl, and I. Lesanovsky, Phys. Rev. Lett. 116, 245701 (2016)

Q 45.4 Thu 12:00 P 104

Structure Formation in a Correlated Rydberg Gas — •Andre Salzinger[1], Elena Kozlikin[2], Martin Pauly[2], Alexander Schuckert[3], Robert Lilow[2], Matthias Bartelmann[2], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Heidelberg — [2]Institut für Theoretische Astrophysik, Heidelberg — [3]Institut für Theoretische Physik, Heidelberg

Cosmic structure formation can be described by a classical path integral formalism. We apply such a theoretical framework to predict structure formation in an initially correlated ensemble of Rydberg atoms. The free Hamiltonian motion of particles and their initial correlation function are contained in a generating functional. We model the non-classical excitation process including blockade and anti-blockade effects to emulate realistic initial conditions. Interactions between the particles are introduced via an operator acting perturbatively on the free generating functional which is evolved in time. Collective properties, such as density correlations can be extracted by applying appropriate operators.

We will discuss different experimental implementations with the aim of directly or indirectly observing the impact of initial correlations on structure formation.

Q 45.5 Thu 12:15 P 104

Many-body dynamics of driven-dissipative Rydberg cavity polaritons — •Tim Pistorius and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

The usage of photons as long-range information carriers has greatly increased the interest in systems with nonlinear optical properties in recent years. The nonlinearity is easily achievable in Rydberg mediums through the strong van der Waals interaction which makes them one of the best candidates for such a system. Here, we propose a way to analyze the steady state solutions of a Rydberg medium in a cavity through the combination of the variational principle for open quantum systems [1] and the P-distribution of the density matrix. To get a better understanding of the many-body-dynamics a transformation into the polariton picture is performed and investigated.

[1] H. Weimer, Variational Principle for Steady States of Dissipative Quantum Many-Body Systems, Phys. Rev. Lett.114, 040402 (2015).

Q 45.6 Thu 12:30 P 104

Pulsed Rydberg four-wave mixing in a microcell — •Fabian Ripka, 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 ondemand 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.

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 coherent 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.

We report on the latest results of Rydberg four-wave mixing in a volume size comparable to the Rydberg interaction range. This scheme promises to enable the creation of non-classical light states.

[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 45.7 Thu 12:45 P 104

Creating $^{23}Na^{40}K$ ground state molecules with detuned STIRAP — •Frauke Seeßelberg[1], Xin-Yu Luo[1], Nikolaus Buchheim[1], Zhenkai Lu[1], Immanuel Bloch[1,2], and Christoph Gohle[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany

Molecules in their absolute vibrational and rotational ground state promise exciting new possibilities for quantum simulation due to their large inducible dipole moments. It is however challenging to obtain molecules, which are sufficiently cold and dense enough for this purpose.

Starting from a near quantum degenerate Bose-Fermi mixture of sodium and potassium we employ stimulated Raman adiabatic passage (STIRAP). STIRAP is a two-photon process, with which we transfer weakly bound heteronuclear NaK Feshbach molecules via an intermediate, excited molecular state in the d/D potential manifold to the molecular ground state. To reduce excessive scattering from near resonant levels in the excited state, we go one-photon detuned with respect to this intermediate molecular level. We experimentally investigate the efficiency of the STIRAP process at various one-photon detunings and compare them with a theoretical model.

Q 45.8 Thu 13:00 P 104

Precision two-color spectroscopy of ^{40}Ca for the determination of the s-wave scattering length — •Veit Dahlke[1], Evgenij Pachomow[1], Eberhard Tiemann[2], Fritz Riehle[1], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

By two-color photoassociation of ^{40}Ca four weakly bound vibrational levels in the Ca$_2$ $X^1\Sigma_g^+$ ground state potential were measured, using highly spin-forbidden transitions to intermediate states of the coupled system $^3\Pi_u$ and $^3\Sigma_u^+$ near the $^3P_1+^1S_0$ asymptote. We have interrogated cold ensembles of about 10^5 calcium atoms trapped in a crossed optical dipole trap at temperatures of approximately 1 μK. The unperturbed binding energies have been measured with kHz accuracy benefiting from few Hertz linewidth offset-locked tunable lasers and detailed lineshape analysis.
From the observed binding energies, including the least bound state, the long range dispersion coefficients $\mathrm{C}_6, \mathrm{C}_8, \mathrm{C}_{10}$ and a precise value for the s-wave scattering length were derived. The precise description of the asymptotic potential was also used to determine scattering lengths for all stable isotopes of calcium.

Q 46: Quantum Gases: Fermions I

Time: Thursday 11:00–13:00 Location: P 204

Group Report Q 46.1 Thu 11:00 P 204

Observation of antiferromagnetic long-range order in the Hubbard model with ultracold atoms — •Daniel Greif, Anton Mazurenko, Christie S. Chiu, Geoffrey Ji, Maxwell F. Parsons, Fabian Grusdt, Richard Schmidt, Marton Kanasz-Nagy, Eugene Demler, and Markus Greiner — Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Quantum gas microscopy of ultracold fermionic atoms in optical lattices opens new perspectives for addressing long-standing open questions on strongly correlated low-temperature phases in the Hubbard model. For example, the precise character of the phases emerging when doping an antiferromagnet away from half-filling is still not well understood. We report on the observation of antiferromagnetic long-range order in a repulsively interacting Fermi gas of Li-6 atoms on a 2D square lattice of approximately 80 sites at temperatures $T/t = 0.25$. Using single-site resolution, the ordered state is directly detected from a peak in the spin structure factor and a diverging correlation length of the spin correlation function. In the long-range ordered state we measure staggered magnetizations exceeding 50% of the ground-state value. When doping away from half-filling into a numerically intractable regime, we find that long-range order extends to doping concentrations of about 15%. Our results pave the way for directly addressing open questions on pseudo-gap states and high-temperature superconductivity.

Q 46.2 Thu 11:30 P 204

Floquet engineering of a two-body system in an array of double wells — •Michael Messer, Rémi Desbuquois, Frederik Görg, Kilian Sandholzer, Gregor Jotzu, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, Switzerland

Periodically driving a system of ultracold fermions in an optical lattice allows for implementing a large variety of effective Hamiltonians through Floquet engineering. A crucial question is whether this method can be extended to interacting systems. By driving a two-body system on an array of double wells we measure the double occupancy and the spin-spin correlator as a function of shaking frequency and strength. We analyze the importance of micromotion to describe the exact time evolution of the system and compare it to numerical theory. In addition we investigate the experimental timescales needed to adiabatically connect the emerging states of the driven system to states of the initial Hamiltonian. We find an adiabatic regime in which the double occupancy and spin-spin correlations of the Floquet Hamiltonian can be exactly compared to theory. This hierarchy of different energy scales allows us to implement driven systems with strong interactions.

Q 46.3 Thu 11:45 P 204

Floquet engineering of unconventional Hubbard terms in an interacting fermionic system — •Frederik Görg, Michael Messer, Gregor Jotzu, Kilian Sandholzer, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Periodically modulated systems have recently attracted much interest both from a theoretical and experimental perspective, since they can be used to create novel effective Hamiltonians which feature terms that are not accessible in static systems. For cold atoms in optical lattices, this approach has, among others, been used to dynamically control the tunnelling amplitude, create artificial gauge fields and spin-dependent lattices. Recently, we experimentally demonstrated how Floquet engineering can be used to create unconventional Hubbard terms for interacting Fermions in an optical lattice. By modulating the lattice position at a frequency close to the interaction energy of a two-body system, we can change both the sign and magnitude of the magnetic exchange energy. For an inhomogeneous cold atom system in a trap, this method can be used to independently tune the exchange coupling and the single particle tunnelling, therefore providing a possible entropy redistribution scheme. An open question in this context is if experimental heating timescales are favourable enough to study this driven interacting many-body system.

Q 46.4 Thu 12:00 P 204

Vanishing order parameter oscillations of the Higgs mode in a cigar-shaped ultracold Fermi gas — •Simon Hannibal[1], Peter Kettmann[1], Mihail Croitoru[2], Vollrath Martin Axt[3], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster — [2]Condensed Matter Theory, University of Antwerp — [3]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 after a large quench from strong to weak interactions. For large aspect ratios we find a dynamical vanishing of the order parameter similar to what has been predicted in the case of a homogeneous system. However, for smaller aspect ratios transverse trap modes are excited preventing a complete vanishing of the order parameter.

Q 46.5 Thu 12:15 P 204

Pair formation in a fermionic system — •Thomas Paintner[1], Daniel Hoffmann[1], Wladimir Schoch[1], Wolfgang Limmer[1], Cheng Chin[2], and Johannes Hecker Denschlag[1] — [1]Universität Ulm, Institut für Quantenmaterie, Deutschland — [2]University of Chicago, James Franck Institute, USA

We investigate the pair formation in a fermionic system at the BEC-BCS crossover. For a given temperature and interaction strength a thermodynamic equilibrium forms between atoms and pairs.

We use a 50-50 mixture of the two lowest ^{6}Li Zeeman states and set their interaction strength by adjusting the scattering length with the help of the Feshbach resonance at 832 G. We then determine the fraction of paired atoms at different temperatures and interaction strengths using optical spectroscopy. The results are compared with a classical calculation [1]. Since the pair formation sets in for higher temperatures than the critical temperature T_c for superfluid transition our results provide a deeper insight into pairing and the pseudo-gap in fermionic systems.

[1] C. Chin et al., *Physical Review A* 69, 033612 (2004).

Q 46.6 Thu 12:30 P 204

Phase Separation in a Bose-Fermi Mixture of ^{41}K and ^{6}Li — •Rianne S. Lous[1,2], Bo Huang[1], Isabella Fritsche[1,2], Fabian Lehmann[1,2], Michael Jag[1,2], Emil Kirilov[1,2], and Rudolf Grimm[1,2] — [1]IQOQI, Austrian Academy of Sciences, Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, Innsbruck, Austria

We report on the observation of phase separation between a ^{41}K Bose-Einstein condensate (BEC) and a ^{6}Li Fermi sea with strong repulsive interspecies interactions. After evaporation in an optical dipole trap, we obtain 10^4 ^{41}K atoms with a 55 % BEC fraction and a Fermi sea of 10^5 ^{6}Li atoms with a $T/T_F < 0.07$. We explore this double-degenerate mixture by tuning the heternonuclear interaction with the use of a Feshbach resonance at 335.8 G. We observe the phase separation by measuring the breathing-mode frequency of the bosons and their lifetimes for varying interaction strength. We see an increase in frequency when interactions become strongly repulsive and a decrease in loss rate. To understand our loss rate results, we calculate the spatial overlap between the two components with a mean-field model beyond local density approximation (LDA) and attribute the losses to the three-body recombination. We also calculate the breathing-mode frequency on a LDA level. Both theoretical models fit nicely to our experimental results. This work is supported by the Austrian Science Fund FWF within SFB FoQuS.

Q 46.7 Thu 12:45 P 204

High-momentum tails as magnetic-structure probes for strongly correlated SU(N) fermionic mixtures in one-dimensional traps — Jean Decamp[1], •Johannes Jünemann[2,3], Mathias Albert[1], Matteo Rizzi[2], Anna Minguzzi[4], and Patrizia Vignolo[1] — [1]Université Côte d'Azur, CNRS, INLN, France — [2]Johannes Gutenberg-Universität, Mainz, Germany — [3]MAINZ-Graduate School Materials Science in Mainz, Mainz, Germany — [4]Université Grenoble-Alpes, CNRS, LPMMC, Grenoble, France

We consider the experimentally feasible setup of a repulsively interacting multi-component Fermi gas under harmonic confinement exhibiting a SU(N) symmetry. Here, we concentrate on the density- and momentum-distributions of the particles, and in particular on their Tan contact (weight of a k^{-4}-scaling in the tails of the mom.-distribution).

For infinite interactions, we show a direct correspondence between the value of the Tan contact for each of the N components of the gas and the Young tableaux for the S_N permutation symmetry group. A mapping to an effective spin-model allows us to identify the corresponding magnetic structure. Measurement of the Tan contact therefore opens an alternative route to the experimental determination of magnetic configurations in cold atomic gases, employing only standard (spin-resolved) time-of-flight techniques.

For finite interactions, we present an analytical scaling prediction for the Tan contact. We confirm the prediction through MPS/DMRG-calculations and show their qualitative agreement with recent experiments.

Q 47: Quantum Computing I

Time: Thursday 14:30–16:15 Location: P 2

Group Report Q 47.1 Thu 14:30 P 2

Generation and application of scalable entanglement in an ion trap — •Thomas Ruster, Henning Kaufmann, Jonas Schulz, David von Lindenfels, Vidyut Kaushal, Christian T. Schmiegelow, Ferdinand Schmidt-Kaler, and Ulrich Poschinger — Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Entanglement is an important resource for applications such as quantum computation and high precision sensing. In a segmented Paul trap, entanglement can be created by combining laser-driven logic gates and ion-shuttling operations. We present how we encode a qubit with coherence times in the 1 s range in the valence electron spin of ^{40}Ca$^+$ ions. The implementation of the set of shuttling operations required for scalable protocols is outlined. We show how to conduct high-fidelity gate operations, which are insensitive against motion excited by the shuttling operations.

We combine gate and shuttling operations to generate a 4-ion GHZ state $|\uparrow\uparrow\uparrow\uparrow\rangle + |\downarrow\downarrow\downarrow\downarrow\rangle$. By applying dynamical decoupling techniques, we can keep the entangled state alive for about 1 s.

As an application of spatially distributed entanglement, we employ Bell states $|\uparrow\downarrow\rangle+|\downarrow\uparrow\rangle$ for sensing inhomogeneous magnetic fields. These states accumulate a phase, which depends on the magnetic field difference between the locations of the constituent ions. By measuring the accumulated phase, we map out dc magnetic fields with accuracies down to 270 pT.

Q 47.2 Thu 15:00 P 2

Adaptive selective addressing of microwave-driven trapped ion qubits — •Patrick Huber, Theeraphot Sriarunothai, Sabine Wölk, Gouri Giri, and Christof Wunderlich — Department Physik, Universität Siegen, 57068 Siegen, Germany

Cold ions stored in Paul traps are well suited for experiments in quantum information science. Applying a spatially varying magnetic field results in a MAgnetic Gradient Induced Coupling (MAGIC) between ions and allows for conditional quantum dynamics. Due to this gradient qubit resonances are individually shifted and become position dependent, thereby making them addressable in frequency space. We apply microwave pulses to realize single qubit gates, to control conditional gates with several ions, and for dynamical decoupling. Such quantum gates rely on the precise knowledge of qubit resonance frequencies that may, however, vary during the execution of a quantum algorithm. Here we report on the implementation of adaptive individual addressing of trapped ion qubits, that is, we measure resonance frequencies periodically using Ramsey interferometry and adapt the microwave pulses' frequency accordingly. First experiments showed that the application of this method results in a twelve-fold reduction of the width of the resonance frequencies' distribution. This improvement in determining qubit resonances is expected to lead to a significant improvement of the fidelity of multi-qubit conditional quantum gates.

Q 47.3 Thu 15:15 P 2

The equivalence of static and dynamic magnetic gradient induced coupling — •Sabine Wölk and Christof Wunderlich — Department Physik, Universität Siegen, 57068 Siegen, Germany

A laser-less interaction between internal and motional states of trapped ions can be induced by a static [1] or by a dynamic [2] magnetic gradient field. Taking advantage of such Magnetic Gradient Induced Coupling (MAGIC), conditional quantum dynamics with effective spin states and motional states can be carried out which is useful for a variety of experiments in quantum information science.

Here, we show that the coupling mechanism in the presence of a dynamic gradient is the same, in a dressed state basis, as in the case of a static gradient [3]. This insight can be used to overcome demanding experimental requirements when using a dynamic gradient field. At the same time it opens new experimental perspectives when using a dynamic gradient field by taking advantage of long range coupled ions, for example, for multi-qubit dynamics.

[1] F. Mintert and Ch. Wunderlich, Phys. Rev. Lett. **87**, 257904 (2001)
[2] C. Ospelkaus et al., Nature **476**, 181 (2011)
[3] S. Wölk and Ch. Wunderlich, arXiv: 1606.04821

Q 47.4 Thu 15:30 P 2

Quantum supremacy via simulation of Ising models on the

square lattice. — Juan Bermejo-Vega[1], •Dominik Hangleiter[1], Martin Schwarz[1], Jens Eisert[1], and Robert Raussendorf[2] — [1]Fachbereich Physik, Institut für theoretische Physik, Freie Universität Berlin — [2]Department of Physics and Astronomy, University of British Columbia, Vancouver, Canada

An important near-term goal in the field of quantum simulation is to demonstrate *quantum supremacy* in the lab by performing a simple experiment whose outcome cannot efficiently be predicted on a classical computer. Here, we propose a wide range of architectures and settings constructed from simple building blocks that show quantum supremacy. Specifically, we show that efficiently classically simulating the dynamics of translation-invariant Ising models on the 2D square lattice is impossible even for a constant time assuming three reasonable complexity-theoretic conjectures to hold. Our proposal requires translation-invariant on-site measurements on the square lattice. We discuss trade-offs in experimental resources relevant to different possible physical architectures, as well as variants of specific assumptions that enter the complexity-theoretic arguments. Our proofs invoke ideas from measurement-based quantum computation. Finally, we show how all considered state preparations can be certified using translation-invariant local measurements. This yields a rigorous certificate that the measurement outcomes originate from the considered distribution giving rise to the situation in which the correctness of the quantum state preparation can be certified.

Q 47.5 Thu 15:45 P 2

An efficient quantum algorithm for spectral estimation — •Adrian Steffens[1,2], Patrick Rebentrost[2], Iman Marvian[2], Jens Eisert[1], and Seth Lloyd[2,3] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin — [2]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139 — [3]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

We develop an efficient quantum implementation of an important signal processing algorithm for line spectral estimation: the matrix pencil method, which determines the frequencies and damping factors of signals consisting of finite sums of exponentially damped sinusoids. Our algorithm provides a quantum speedup in a natural regime where the sampling rate is much higher than the number of sinusoid components. Along the way, we develop techniques that are expected to be useful for other quantum algorithms as well – consecutive phase estimations to efficiently make products of asymmetric low rank matrices classically accessible and an alternative method to efficiently exponentiate non-Hermitian matrices. Our algorithm features an efficient quantum-classical division of labor: The time-critical steps are implemented in quantum superposition, while an interjacent step, requiring only exponentially few parameters, can operate classically. We show that frequencies and damping factors can be obtained in time logarithmic in the number of sampling points, exponentially faster than known classical algorithms.

Q 47.6 Thu 16:00 P 2

Fidelity witnesses for certifying digital quantum simulations of fermionic linear optics — •Marek Gluza[1], Martin Kliesch[2], Jens Eisert[1], and Leandro Aolita[3] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany — [2]National Quantum Information Centre, University of Gdansk, Poland — [3]Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

Recently, digital quantum simulations in platforms based on trapped ions, cavity QED and superconducting circuits have been reported in which systems consisting of few qubits were evolved under a programmable set of gates. These studies were successfully certified by quantum state tomography, which will not be possible in future simulations of larger systems due to the exponential growth of the Hilbert space dimension.

We address this conceptual issue by employing ideas of geometrical separation and importance sampling in order to construct a fidelity witness. Specifically, we provide a method to efficiently certify preparations of pure Gaussian fermionic target states, which are captured by the formalism of fermionic linear optics. Moreover, we apply our fidelity witness to dynamical quenches in the paradigmatic critical transverse field Ising model and additionally describe possible applications to adiabatic quantum computation. The number of state preparations needed to certify the fidelity of prepared states is a polynomial of a small degree in the number of the system's constituents, which allows for the certification of scalable quantum simulations.

Q 48: Optomechanics I

Time: Thursday 14:30–15:45 Location: P 4

Q 48.1 Thu 14:30 P 4

Orientational localization in the CSL model — •Björn Schrinski, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

Recent experimental progress in the control of anisotropic levitated nano-particles [1-3] holds the promise of accessing the orientational degrees of freedom in the quantum regime and thus testing macrorealistic modifications of quantum mechanics. Here, we discuss how the model of continuous spontaneous localization (CSL) [4] affects the orientational coherence of a nano-particle. In particular, we determine the resulting spatio-orientational localization rates and examine how the angular momentum diffusion might help to improve on existing CSL tests.

[1] Kuhn et al., Nano Letters 18, 5604 (2015)
[2] Hoang et al., Phys. Rev. Lett. 117, 123604 (2016)
[3] Kuhn et al., arXiv: 1608.07315 (2016)
[4] Bassi et al., Rev. Mod. Phys. 85, 471 (2013)

Q 48.2 Thu 14:45 P 4

Orientational decoherence of nanoparticles — •Birthe Papendell, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

Motivated by trapping and cooling experiments with nonspherical nanoparticles [1-4] we discuss how their rotational quantum dynamics is affected by photon scattering or the interaction with a gaseous environment. We present the localization rate for gas collisions off a van der Waals-type potential and for Rayleigh scattering off a symmetric or an asymmetric dielectric nanoparticle. Finally we show in what sense the associated master equation describes angular momentum diffusion [5].

[1] S. Kuhn, P. Asenbaum, A. Kosloff, M. Sclafani, B. A. Stickler, S. Nimmrichter, K. Hornberger, O. Cheshnovsky, F. Patolsky, and M. Arndt, Nano Lett. 15, 5604 (2015).
[2] B. A. Stickler, S. Nimmrichter, L. Martinetz, S. Kuhn, M. Arndt, and K. Hornberger, Phys. Rev. A 94, 033818 (2016).
[3] T. M. Hoang, Y. Ma, J. Ahn, J. Bang, F. Robicheaux, Z.-Q. Yin, and T. Li, Phy. Rev. Lett. 117, 123604 (2016).
[4] S. Kuhn, A. Kosloff, B. A. Stickler, F. Patolsky, K. Hornberger, M. Arndt, and J. Millen, arxiv: 1608.07315 (2016).
[5] B. A. Stickler, B. Papendell, and K. Hornberger, Phys. Rev. A 94, 033828 (2016).

Q 48.3 Thu 15:00 P 4

Rotational optomechanics with levitated nanorods — •Stefan Kuhn[1], Benjamin A. Stickler[2], Alon Kosloff[3], Fernando Patolsky[3], Klaus Hornberger[2], Markus Arndt[1], and James Millen[1] — [1]University of Vienna, Faculty of Physics, VCQ, Boltzmanngasse 5, 1090 Vienna, Austria — [2]University of Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany — [3]School of Chemistry, Tel-Aviv University, Ramat-Aviv 69978, Israel

Optical control over nano-mechanical structures has become invaluable for force sensing applications and tests of fundamental quantum physics. To achieve the optimal performance of such devices, their coupling to the environment needs to be minimized. This can for instance be achieved by levitating nanoparticles in external fields which has led to a growing interest in the field of levitated optomechanics. Here we extend this work to the rotational motion of optically trapped silicon nanorods[1]. We track and manipulate both their linear and rotational motion in the field of two counter-propagating, focussed laser beams via the light polarization. In this way we gain full control over the ro-translational dynamics of the rod. We will discuss the prospects of our levitated systems for realising rotational optomechanics[2,3], single particle thermodynamics and as a novel source for high-mass matter-wave interferometry experiments.

[1] S. Kuhn et al., arXiv:1608.07315 (2016)
[2] S. Kuhn et al., Nano Lett., 15(8), 5604-5608 (2015)
[3] B. A. Stickler et al., Phys. Rev. A, 94, 033818 (2016)

Q 48.4 Thu 15:15 P 4

Cavity optomechanics with levitated nanospheres at low pressures — •Uros Delic, David Grass, Nikolai Kiesel, and Markus Aspelmeyer — Faculty of Physics, University of Vienna, Vienna, Austria

In recent years cavity cooling of levitated nanospheres has been demonstrated in multiple experiments [1, 2]. However, regime of high cooperativity $C > 1$ is yet to be reached, leading to ground state cooling of nanosphere center-of-mass motion and full quantum control of nanosphere motion. A common obstacle in many experiments is stable levitation of nanospheres at low pressures, which has so far been shown in hybrid electro-optical systems [2] and in optical tweezers [3, 4].

We report on progress of combining stable optical levitation in optical tweezers with an optical cavity to reach a regime of high cooperativity at low pressures. We will present first results on coupling a nanosphere levitated by tweezers to the optical cavity. We will discuss further improvements to the experiment necessary to reach quantum control of nanosphere motion.

[1] Kiesel et al., PNAS 110: 14180-14185 (2013) [2] Millen et al., Phys. Rev. Lett. 114, 123602 (2015); Millen et al., Phys. Rev. Lett. 117, 173602 (2016) [3] Jain et al., Phys. Rev. Lett. 116, 243601 (2016) [4] Mestres et al., Appl. Phys. Lett. 107, 151102 (2015)

Q 48.5 Thu 15:30 P 4

Nonlinear Quantum Optics in Nanophotonic Waveguides — •Hashem Zoubi and Klemens Hammerer — Leibniz University Hannover, Germany

We develop a systematic method for deriving a quantum optical multimode Hamiltonian for the interaction of photons and phonons in nanophotonic dielectric materials by applying perturbation theory to the electromagnetic Hamiltonian [1]. The Hamiltonian covers radiation pressure and electrostrictive interactions on equal footing. As a paradigmatic example, we apply our method to a cylindrical nanoscale waveguide, and derive a Hamiltonian description of Brillouin quantum optomechanics. We show analytically that in nanoscale waveguides radiation pressure dominates over electrostriction, in agreement with recent experiments. We explore the possibility of achieving a significant nonlinear phase shift among photons propagating in nanoscale waveguides exploiting interactions among photons that are mediated by vibrational modes and induced through Stimulated Brillouin Scattering (SBS) [2]. We introduce a configuration that allows slowing down the photons by several orders of magnitude via SBS involving sound waves and two pump fields. We extract the conditions for maintaining vanishing amplitude gain or loss for slowly propagating photons while keeping the influence of thermal phonons to the minimum. The nonlinear phase among two counter-propagating photons can be used to realize a deterministic phase gate.

[1] H Zoubi, K Hammerer, arXiv:1604.07081 (Phys. Rev. A, in press). [2] H Zoubi, K Hammerer, arXiv:1610.03355.

Q 49: Ultrashort Laser Pulses: Generation and Applications

Time: Thursday 14:30–16:45 Location: P 5

Q 49.1 Thu 14:30 P 5

Frequency conversion from the near-infrared to the deep UV with an MgO crystal — •Dennis Mayer, Mario Niebuhr, Christian Matthaei, Axel Heuer, and Markus Gühr — Institut für Physik und Astronomie, Universität Potsdam

Femtosecond pulses in the deep and vacuum ultraviolet region are ideal probes for ultrafast molecular and solid state photoelectron spectroscopy. Due to the recent progress in amplified high repetition rate sources, the nonlinear conversion schemes established at kHz repetition rates need to be scaled to a regime of higher average flux and lower per pulse energy. Newly established solid state harmonic generation provides advantages over conventional gas phase harmonic generation in terms of the conversion efficiency [1]. However, this comes at the cost of higher absorption and shorter effective harmonic generation length.

We concentrate on the generation of harmonics in wide bandgap insulators and on the harmonics emitted below the bandgap. We utilize a 100 kHz amplified Yb:KGW system and present a systematic study of femtosecond nonlinear conversion in MgO.

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

Q 49.2 Thu 14:45 P 5

Development and characterization of a pulse preserving XUV multilayer monochromator — •Tanja Neumann[1], Yudong Yang[2], Roland Mainz[2], Franz Kärtner[2], and Thorsten Uphues[1] — [1]CFEL, Attosecond Research and Science Group, Hamburg University, Luruper Chaussee 149, 22761 Hamburg — [2]Center for Free-Electron Laser Science, DESY and Department of Physics, University of Hamburg, Hamburg, Germany

HHG based time-resolved experiments in the XUV are a key technologie to study atomic, surface and chemical processes in realtime. Some of these experiments require high energy resolution to distinguish between spin compenents or resolve chemical shifts in the corresponding energy spectra. In the frame work of a master thesis a narrow bandwidth multilayer mirror monochromator (MMM) was developed for separation and energy tunability of a well defined spectral bandwidth from a high order harmonic spectrum generated by 25 femtosecond laser pulses at 800 nm central wavelength. The MMM is tailored to the experimental requirements of a surface experiment and is able to select a defined bandwidth of less than 1 eV from the harmonic spectrum in the photon energy range between 90 and 98 eV. For time resolved experiments it designedto be used at the same time to recombine the laser pulse and the XUV pulse and focus them down to the experiment maintaining temoral and spectral overlap in the given energy range. A major advantage of the MMM is the preservation of the time structure of the XUV and laser pulse, thus addition dispersion correction is not needed.

Q 49.3 Thu 15:00 P 5

Design and testing of a setup for 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, Germany — [2]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [3]Heriot-Watt University, Edinburgh, EH14 4AS, United Kingdom

Ultrashort pulsed lasers with a duration of a single oscillation of the electric field are an ideal tool to investigate the sub-cycle dynamics of electrons under an intense field [1] as the temporal contrast is increased. Recent observation of rescattering physics at nanotips with the aid of optical field enhancement suggests that the strong-field regime can be reached with pulse energies even below 1 nJ [2]. Commercial laser systems in the nJ-regime such as Ti:sapphire oscillators however are limited to pulse durations around two optical cycles. Here 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 down to 3 fs corresponding to a single optical cycle. A MIIPS pulse characterization scheme for various overlapping spectral ranges was realized and used to test the pulse compressor.

[1] M. T. Hassan et al., Rev. Sci. Instrum. **83**, 111301 (2012).

[2] M. Krüger, M. Schenk and P. Hommelhoff, Nature **475**, 78 (2011).

Q 49.4 Thu 15:15 P 5

Design and simulation of a NOPA for the pulse diagnostics XUV PUMA at FLASH, DESY — •Niklas Borchers[1,2], Martin Büscher[1,2], Mark Prandolini[3], Sven Toleikis[3], Bert Struve[1], and Ulrich Teubner[1,2] — [1]Institut für Laser und Optik, Hochschule Emden/Leer, D-26723 Emden — [2]Institut für Physik,

Universität Oldenburg, D-26129 Oldenburg — [3]Deutsches Elektronen-Synchrotron DESY, D-22607 Hamburg

To allow precise measurement of the jitter and pulse duration of free electron lasers such as FLASH on a shot to shot basis novel techniques are necessary. Of course, this is a difficult task in the extreme ultra violet spectral region (4.2 to 45nm; XUV), in particular in combination with the ultrashort time scales (<50fs). A corresponding diagnostic which is based on a plasma gate is XUV PUMA (Pulsdauermeßapparatur), which is currently under development. As the resolution is mainly limited by the probe pulse, ultrashort tunable sub- 30fs pulses in a range from 580nm to 680nm wavelength with a pulse energy $>1\mu$J are required for the cross correlator as one key element of the diagnostics. The pulses will be generated with a NOPCPA (non-collinear optical parametric chirped pulse amplifier). Prior to set-up, the NOPCPA has been simulated in all major aspects (SHG, dispersion, efficiency, etc.) using a tailored MATLAB program. With the aid of the simulation, a compact system, as required by the FLASH beamline end station, has been designed to optimally match the parameters required by the XUV PUMA. This work is sponsored by BMBF 05K16ME1.

Q 49.5 Thu 15:30 P 5

Non-Collinear Circular Polarized High Harmonic Generation — •Patrik Grychtol[1], Jennifer Ellis[1], Kevin Dorney[1], Carlos Hernández-García[2], Franklin Dollar[1], Christopher Mancuso[1], Tinting Fan[1], Dmitriy Zusin[1], Christian Gentry[1], Charles Durfee[3], Daniel Hickstein[1], Henry Kapteyn[1], and Margaret Murnane[1] — [1]JILA-NIST and Department of Physics, University of Colorado, Boulder, CO 80309, USA — [2]Grupo de Investigación en Aplicaciones del Láser y Fotónica, Departamento de Física Aplicada, University of Salamanca, Spain — [3]Department of Physics, Colorado School of Mines, Golden, CO 80401, USA

The process of high harmonic generation (HHG) allows for producing attosecond bursts of extreme ultraviolet and soft x-ray light on the tabletop. HHG sources are ideal tools for a variety of scientific and technologically important applications, such as imaging of nanoscale material properties, ultrafast spectroscopy of photoelectrons or element-specific characterization of spin dynamics. While the emission of bright HHG radiation had been limited to linear polarization for quiet a long time, recent exciting breakthroughs have demonstrated the production of high harmonic beams with controllable polarization using two counter-rotating circularly polarized driving laser beams in a collinear or non-collinear geometry. This contribution will focus on the non-collinear case, which offers several key benefits, such as the polarization selective angular separation of the harmonics without a spectrometer. Furthermore, it will be demonstrated how full phase-matching in a non-collinear geometry can be achieved.

Q 49.6 Thu 15:45 P 5

Synchronous interaction of free electrons with optical evanescent wave excited by femtosecond laser pulses — •Martin Kozak, Paul Beck, Joshua McNeur, Norbert Schönenberger, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen

In recent years, the coherent interaction between optical near-fields and free-electrons became the basis for several experimental techniques focused on electron acceleration (dielectric laser accelerators, DLAs [1]) or energy-resolved electron imaging (photon-induced near-field electron microscopy, PINEM [2]). In classical DLA schemes, the synchronous near-field mode is excited by femtosecond laser pulse on top of a periodic dielectric element with period smaller than the laser wavelength [1]. Preparation of such a nanoscale phase-mask elements requires advanced nanofabrication. In this contribution we show the first demonstration of the synchronous interaction between free propagating electrons and an evanescent optical wave excited by total internal reflection on the flat surface of high-refractive index dielectrics. The maximum observed energy modulation is comparable to the grating-based DLA and is limited by the electron group velocity dephasing with respect to the phase velocity of the evanescent wave. Light coupling to the synchronous evanescent wave can be in future improved using the evanescent field of a transverse magnetic mode guided in an optical waveguide. [1] J. Breuer, and P. Hommelhoff, Phys. Rev. Lett. 111, 134803 (2013). [2] B. Barwick, D. J. Flannigan, and A. H. Zewail, Nature 462, 902-906 (2009).

Q 49.7 Thu 16:00 P 5

Ultrashort pulsed compact 2050 nm fiber laser accelerating electrons at a dielectric structure — Heinar Hoogland[1,2], Joshua McNeur[2], Martin Kozák[2], •Peter Hommelhoff[2], and Ronald Holzwarth[1] — [1]Menlo Systems GmbH, Am Klopferspitz 19a, 82152 Martinsried, Germany — [2]Lehrstuhl für Laserphysik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen, Germany

A robust all-polarization maintaining fiber laser system at 2050 nm emitting femtosecond pulses at 1-MW peak power level is studied for subsequent dielectric laser acceleration of non-relativistic electrons. The laser setup consists of a Thulium/Holmium codoped gain fiber based oscillator in figure-9 design and a pulse picked chirped pulse two-stage amplifier arrangement. Both temporal stretching as well as recompression of the 2050 nm pulses are achieved by exploiting a single chirped volume Bragg grating, circumventing a bulky diffraction grating based temporal pulse management solution that is highly prone to mechanical perturbations. The laser emits strictly linear polarized pulses at 370-fs pulse duration and 570 nJ pulse energy. By applying this compact fiber laser architecture to a table-top sized "teeny-tiny" accelerator device based on a single Silicon nanograting, 25-keV electrons are accelerated by gradients up to 53 MeV/m. The overall compactness of the entire experimental stage allows for drastically reduced electron accelerator dimensions over traditional large-scale radio-frequency linear accelerator arrangements.

Q 49.8 Thu 16:15 P 5

Temporal characterization of femtosecond electron bunches in a laser-triggered scanning electron microscope — •Norbert Schönenberger, Martin Kozák, Joshua McNeur, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen

To study the dynamics in atomic and condensed matter systems, including phonon excitations and electron dynamics in atoms and molecules, sub-femtosecond timescales need to be resolved. The temporal resolution of these ultrafast experiments with electron beams is limited by both the electron dispersion in vacuum and the Coulomb repulsion between electrons. Here we present the temporal characterization of electron bunches emitted from a Schottky-type tip source inside a standard scanning electron microscope (SEM). Photoemission from the tip is induced by 100 fs ultraviolet pulses. The temporal profile of the bunch is obtained by energy- and time-resolved cross-correlation measurements between the electron bunch and the electromagnetic near-field mode of an infrared laser pulse traversing a periodic dielectric nanostructure. We study the influence of the bunch charge and the settings of the electron column on the longitudinal behaviour of the electron packets emitted from the tip to gain further insight into the behaviour of new electron sources, sub-femtosecond-resolved dielectric laser accelerator (DLA) diagnostics and electron diffraction and microscopy experiments [1].

[1] Martin Kozák, et al. Optical gating and streaking of free-electrons with attosecond precision, arXiv:1512.04394 (2015)

Q 49.9 Thu 16:30 P 5

Ultrafast laser fabrication of biomimetic micro and nano structured surfaces — •Evangelos Skoulas — N.Plastira 100, Heraclion, Greece

We report on the fabrication of artificial biomimetic surfaces fabricated via femtosecond laser processing. Metallic, semiconductor and dielectric surfaces were irradiated and Laser Induced Surface Structures (LIPSS) were observed in each type of material surface. In particular femtosecond laser pulses with linear, circular, radial and azimuthal polarization states were utilized for structuring steel (metallic), silicon (semiconductor) and fused silica (dielectrics) surfaces. Experimental results showed that the direction of LIPSS in each case proved to be polarization dependent. A complete study was carried out for the investigation and understanding of LIPSS dependence on fluence value and the number of pulses per spot at two different wavelengths of irradiation enabling the creation of new and more complex surface structures. Furthermore, different LIPSS morphologies and geometries were observed. Additionally large area surfaces were fabricated, tailored with various micro and nano structures bearing great structural resemblance with surfaces found in nature such as lotus leaf, shark skin and butterfly Greta Oto wing. Those bioinspired surfaces were found to exhibit remarkable optical and wetting properties which were attributed to the specific laser induced surface morphology. Thus femtosecond laser processing can be a novel and one single-step method for the fabrication of functional surfaces on almost all classes of solid materials.

Q 50: Matter Wave Optics

Time: Thursday 14:30–16:00 Location: P 11

Q 50.1 Thu 14:30 P 11

Light-shift effects in light-pulse atom interferometry — •Alexander Friedrich[1], Enno Giese[2], Sven Abend[3], Wolfgang P. Schleich[1], and and Ernst M. Rasel[3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm. — [2]Department of Physics, University of Ottawa. — [3]Institut für Quantenoptik, Leibniz Universität 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. Retro-reflective setups with two counterpropagating lattices reduce the effect of wave-front distortions and mirror vibrations. However, this advantage comes at the cost of a light-shift contribution to the interferometer phase due to off-resonant transitions. In Raman diffraction the impact of light-shifts is well understood.[1,2] For Bragg diffraction we have recently made significant progress and demonstrated that this intrinsic effect of beam splitters can be suppressed to a large extend by appropriately chosen pulse envelopes.[3] In our contribution we investigate mitigation strategies as well as different interferometer geometries.

[1] A. Gauguet et al., Phys. Rev. A **78**, 043616 (2008)
[2] T. Lévèque et al., Phys. Rev. Lett. **103**, 080405 (2009)
[3] E. Giese, A. Friedrich et al., Phys. Rev. A, (2016) (*accepted*)

A.F. is grateful to the Center for Integrated Quantum Science and Technology (IQ^{ST}) for funding.

Q 50.2 Thu 14:45 P 11

Interparticle interactions in atom interferometry — •Christian Ufrecht, Albert Roura, Wolfgang P. Schleich, and the QUANTUS team — Institut für Quantenphysik, Universität Ulm

In recent years, high-precision atom interferometry has attracted a lot of attention. In particular, light pulse interferometers with macroscopic arm separations and Bose-Einstein condensates as highly coherent atom sources provide enormous potential to measure e.g. field gradients with unprecedented accuracy. Interactions between the atoms, however, seem to limit the precision in phase measurements and introduce mean-field shifts. To better understand these effects, we translate the formalism of Ref. [1] into second quantization, where the inclusion of interactions is straightforward. The choice of a particular interaction picture helps us to split the problem in two parts: (i) A free evolution which is equivalent to Ref. [1], and (ii) an interaction which acts upon this result. Our approach identifies the effects purely originating from the interaction.

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.

[1] Kleinert, S., Kajari, E., Roura, A. and Schleich, W. P., Phys. Rept. 605, 1-50 (2015)

Q 50.3 Thu 15:00 P 11

Excitation of Strongly Interacting Moving Rydberg Atoms by Photon Recoil Momentum — •Razmik Unanyan — University of Kaiserslautern, Germany

Based on isomorphism between an ensembles of Rydberg atoms in resonant laser fields in the limit of complete dipole blocking and the Jaynes-Cummings model we propose a scheme for robust and efficient excitation of atomic Rydberg state by photon-momentum recoil. It is shown that the Doppler frequency shifts, due to atomic motion can play an important role in adiabatic population transfer processes of atomic internal states by a pair of laser fields. For the limiting case of slow atoms (Doppler shift much smaller than the photon recoil energy) the Rydberg state does not become populated regardless of the order of switching of laser fields, while for the case of fast atoms interacting with the intuitive sequence of pulses, the target state is the state with single Rydberg excitation. It is shown that these processes are robust with respect to parameter fluctuations, such as the laser pulse area and the relative spatial offset (delay) of the laser beams.

Q 50.4 Thu 15:15 P 11

Discrete-Time Quantum Walks in Momentum Space — •Caspar Groiseau[1] and Sandro Wimberger[1,2,3] — [1]ITP, Heidelberg University — [2]DiFeST, Parma University — [3]INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma

Quantum random walks differ from their classical analogue by the fact that the state of the walker is in a superposition of positions. This is the consequence of applying at each step of the walk a 'coin toss' operator that creates a superposition of two quantum states in an internal degree of freedom, followed by a conditional position displacement depending on this internal state. In our case, the walkers are atoms of a spinor Bose-Einstein condensate kicked by a periodic optical lattice, for whose description we can exploit the quantum kicked rotor dynamics. The kicks will act as the conditional displacements. For a simple zero-momentum initial state, the walker will just symmetrically diffuse in momentum space. We break the spatial-temporal symmetry by using a directed ratchet motion. The direction of the movement is controlled by the sign of the kicking potential. The sign difference in the kick potential corresponds to a sign difference in the detuning of the kicking laser between two hyperfine levels of the ground state. A concrete realization of this scheme with a Bose-Einstein condensate of Rubidium atoms is currently worked out at Oklahoma [1]. We investigate how the analytic theory of the temporal evolution of the quantum kicked rotor at quantum resonance can be transferred to two internal spin states that are mixed at each step.

[1] G. Summy and S. Wimberger, Phys Rev A 93, 023638 (2016)

Q 50.5 Thu 15:30 P 11

Electric Field Controlled Quantum Reflection — •Benjamin A. Stickler[1], A. Ronny Barnea[2], Tobias Nitschke[1], Uzi Even[2], and Klaus Hornberger[1] — [1]Faculty of Physics, University of Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany — [2]School of Chemistry, Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel

We demonstrate that an electric potential can be used to control quantum reflection of matter waves off periodically microstructured surfaces. An alternating voltage applied between neighboring grating bars induces an electric field which serves to modify the interaction between the surface and the impinging atom so that quantum reflection is suppressed. The experimentally measured reflectivities agree with our simulations and the suppressed reflection probability is reproduced by a simple analytic model.

Q 50.6 Thu 15:45 P 11

Relativistic electron vortex beams in a magnetic field — •Koen van Kruining[1], Armen Hayrapetyan[1], and Jörg Götte[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden — [2]College of Engineering and Applied Sciences, Nanjing University, Nanjing, China

We present a relativistic description of electron vortex beams in a constant magnetic field. Including spin from the beginning reveals a complicated azimuthal current structure, containing small rings of counterrotating current between rings of stronger corotating current. Contrary to many other problems in relativistic quantum mechanics, there exists a set of vortex beams with exactly zero spin-orbit mixing in the highly relativistic and nonparaxial regime. These 'clean' vortex beams possess no azimuthal currents and factorise in an azimuthal phase factor, or vortex charge, and a radial profile. A separation which is typically impossible for nonparaxial vortex beams of any nonzero spin.

Q 51: Ultracold Atoms I

Time: Thursday 14:30–16:30 Location: P 104

Group Report Q 51.1 Thu 14:30 P 104
Optical traps for single ions and Coulomb crystals — •Leon Karpa, Julian Schmidt, Alexander Lambrecht, Pascal Weckesser, Yannick Minet, Fabian Thielemann, Markus Debatin, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs Universität Freiburg, Germany

We demonstrate optical trapping of $^{138}Ba^{+}$ ions without residual rf-confinement for durations of up to 3 s, an improvement in lifetime by 3 orders of magnitude compared to recent experiments[1,2]. With the trapping probability approaching unity for durations of 100 ms combined 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[3].

The presented approach can also be applied for all-optical trapping of Coulomb crystals which we demonstrate by spectroscopy of a crystal excited within the optical trap. We discuss possible applications of our results in the fields of ultracold chemistry and structural quantum phase transitions.

[1] C. Schneider, M. Enderlein, T. Huber and T. Schaetz, Nat. Photon. **4**, 772 (2010)
[2] Huber, A. Lambrecht, J. Schmidt, L. Karpa and T. Schaetz, Nat. Commun. **5**, 5587 (2014)
[3] see e.g.: A. Grier, M. Cetina, F. Orucevic, and V. Vuletic, PRL **102**, 223201 (2009)

Q 51.2 Thu 15:00 P 104
Fictitious magnetic field gradients in optical microtraps as an experimental tool for interrogating and manipulating cold atoms — •Yijian Meng, Bernhard Albrecht, Christoph Clausen, Alexandre Dareau, Philipp Schneeweiss, and Arno Rauschenbeutel — TU Wien/Atominstitut, VCQ, Vienna, Austria

Optical microtraps provide a strong spatial confinement for laser-cooled atoms. They can, e.g., be realized with strongly focused trapping light beams or the optical near fields of nano-scale waveguides and photonic nanostructures. Atoms in such traps often experience strongly spatially varying AC Stark shifts which are proportional to the magnetic quantum number of the respective energy level. These inhomogeneous fictitious magnetic fields can cause a displacement of the trapping potential that depends on the Zeeman state. Hitherto, this effect was mainly perceived as detrimental. However, it also provides a means to probe and to manipulate the motional state of the atoms in the trap by driving transitions between Zeeman states. Furthermore, by applying additional real or fictitious magnetic fields, the state-dependence of the trapping potential can be controlled. Here, using laser-cooled atoms that are confined in a nanofiber-based optical dipole trap, we employ this control in order to tune the microwave coupling of motional quantum states. We record corresponding microwave spectra which allow us to infer the trap parameters as well as the temperature of the atoms. Finally, we reduce the mean number of motional quanta in one spatial dimension to 0.3(1) by microwave sideband cooling.

Q 51.3 Thu 15:15 P 104
An atomic erbium Bose-Einstein condensate generated in a quasistatic optical dipole trap — •Daniel Babik, Jens Ulitzsch, Roberto Röll, and Martin Weitz — Institut für Angewandte Physik, Wegelerstraße 8, 53115 Bonn

We report on the generation of a Bose-Einstein condensate of erbium atoms in a quasistatic optical dipole trap in an experiment aimed at the study of physics of strong light-induced gauge fields. 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 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). It is expected to reach much longer coherence times with erbium in spin-dependent optical lattice experiments and for far detuned Raman manipulation in comparison with alkali atoms.

In our experiment an erbium atomic beam is decelerated by a Zeeman slower using radiation tuned to the 400.91 nm transition of atomic erbium. Following work by the Innsbruck group, we trap erbium atoms in a narrow-line magneto-optical trap near 582.84 nm. Subsequently, we load erbium atoms into the quasistatic dipole potential generated by a focused beam near 10.6 μm wavelength provided by a CO2-laser and cool atoms evaporatively to quantum degeneracy. In the future, we plan to investigate topological states and strong synthetic magnetic fields with the rare earth atomic quantum gas.

Q 51.4 Thu 15:30 P 104
State-dependent transport of neutral atoms in two dimensions — •Gautam Ramola, Stefan Brakhane, Geol Moon, Max Werninghaus, Carsten Robens, Richard Winkelmann, Alexander Knieps, Wolfgang Alt, Dieter Meschede, and Andrea Alberti — Institut für Angewandte Physik, Bonn, Germany

Discrete time quantum walks (DTQWs) offer a versatile platform for exploring quantum transport phenomena involving the delocalization of pseudo-spin-1/2 particles on a lattice. Our recently built 2D state-dependent optical lattice setup provides an ideal platform to simulate topologically protected edge state transport using DTQWs in two dimensions [1]. The 2D quantum simulator makes use of polarization-synthesized lattice beams to deterministically transport neutral Cs atoms based on their internal state [2]. Furthermore, a high numerical aperture (NA = 0.92) objective lens [3] is used for imaging and addressing atoms with single site resolution, enabling us to create sharp boundaries between different topological domains. I will report on the experimental realization of the polarization synthesized optical lattice in two dimensions and on the most recent results.

[1] T. Groh et al. Robustness of topologically protected edge states in quantum walk experiments with neutral atoms, Phys. Rev. A **94** (2016)
[2] C. Robens et al. Fast, high-precision optical polarization synthesizer for ultracold-atom experiments, arXiv:1611.07952 (2016)
[3] C. Robens et al. A high numerical aperture (NA = 0.92) objective lens for imaging and addressing of cold atoms, arXiv:1611.02159 (2016)

Q 51.5 Thu 15:45 P 104
Robustness of Topologically Protected Edge States in Quantum Walk Experiments with Neutral Atoms — •Thorsten Groh[1], Stefan Brakhane[1], Wolfgang Alt[1], Dieter Meschede[1], Janos Karoly Asbóth[2], and Andrea Alberti[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany — [2]Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Hungarian Academy of Sciences, H-1525 Budapest, P.O. Box 49, Hungary

Discrete time quantum-walks (DTQWs) with trapped ultracold atoms offer a versatile platform for the experimental investigation of topological insulator materials. An experimental proposal based on neutral atoms in spin-dependent optical lattices to realize one- and two-dimensional discrete-time quantum walks (DTQWs) with spatial boundaries between distinct Floquet topological phases is presented.

The robustness of topologically protected edge states arising at the boundaries separating distinct topological domains is analyzed in the presence of experimentally induced decoherence. Under realistic decoherence conditions, the experimental feasibility to observe unidirectional, dissipationless transport of matter waves along topological boundaries is investigated. [1]

[1] T. Groh, S. Brakhane, W. Alt, D. Meschede, J. K. Asbóth, and A. Alberti, "Robustness of topologically protected edge states in quantum walk experiments with neutral atoms," Phys. Rev. A 94, 013620 (2016).

Q 51.6 Thu 16:00 P 104
Implementing supersymmetric dynamics in ultracold atom systems — •Martin Lahrz, Christof Weitenberg, and Ludwig Mathey — Universität Hamburg, Hamburg, Germany

Supersymmetry plays an essential role in solvable quantum mechanical problems, ranging from the hydrogen atom to soliton physics. The solvability of these systems can be traced back to supersymmetric partner Hamiltonians and their isospectral features. In this talk, we propose a detailed experimental setup for ultracold atom systems to realize such a pair of supersymmetric Hamiltonians. To test their supersymmetric relation, we propose a Mach–Zehnder interference experiment that can be realized with current technology. It compares the dynamics of a coherently split wave packet under these Hamiltonians. The contrast of the resulting interference pattern gives a sharp signal if the Hamiltonians form a supersymmetric pair. This proposal establishes ultracold atom dynamics and matter–wave interferometry as a device to test sophisticated features of quantum mechanical systems with clarity.

Q 51.7 Thu 16:15 P 104

The PRIMUS-Project; an optical dipole trap under microgravity — •Christian Vogt[1], Sascha Kulas[1,2], Andreas Resch[1], Sven Herrmann[1], Claus Lämmerzahl[1], and the PRIMUS-Team[1,3] — [1]ZARM, Universität Bremen — [2]JPL, Pasadena, USA — [3]Institut für Quantenoptik, LU Hannover

Matter wave interferometry in microgravity offers the potential of largely extended interferometry times and thus precision measurements with much increased sensitivity. Motivated by this prospect, a large effort is currently underway to advance the necessary technology and perform first such atom optical experiments on microgravity platforms such as drop towers, zero-g airplanes or sounding rockets. The QUANTUS collaboration has thereby established a magnetic chip trap as a compact and efficient source of matterwaves for such microgravity cold atom experiments. Within the PRIMUS experiment we pursue another approach and set up an optical dipole trap as an alternative source for matter wave interferometry in microgravity. While this comes with additional technical challenges, it also offers several benefits, such as the possible application of Feshbach resonances, improved harmonicity of the trap or the trapping of all mF states. To implement the dipole trap we use a high power laser at 1960nm wavelength and load atoms directly from a Rb magneto optical trap. Here we will report on the current status and first results from the project. The PRIMUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50 WM 1642.

Q 52: Quantum Gases: Fermions II

Time: Thursday 14:30–16:45 Location: P 204

Q 52.1 Thu 14:30 P 204

Observation of a dynamical topological phase transition — •Benno Rem[1], Nick Fläschner[1], Dominik Vogel[1], Matthias Tarnowski[1], Dirk-Sören Lühmann[1], Markus Heyl[2], Jan Budich[3], Ludwig Mathey[1], Klaus Sengstock[1], and Christof Weitenberg[1] — [1]ILP, ZOQ, CUI, Universität Hamburg — [2]Physik Department, TU München — [3]IQOQI, ITP, Universität Innsbruck

Topological phases are characterized by a non-local order and constitute a exotic form of matter. The paradigmatic Haldane model on a hexagonal lattices features topologically distinct phases characterized by the Chern number. Recently, quenches in such models have attracted particular attention and it was pointed out that while a Hall response builds up dynamically, the Chern number of the wave function cannot change across the quench. Instead the dynamical evolution will feature Fisher zeros in the Loschmidt amplitude, which give rise to what is called a dynamical phase transition. Here, we experimentally study this dynamical evolution using a time- and momentum-resolved state tomography for spin-polarized fermionic atoms in driven optical lattices [1]. At a critical time after a sudden quench, we observe the appearance, movement and annihilation of dynamical vortices in momentum space [2]. We identify them as the Fisher zeros, which signal the dynamical phase transition. Our results pave the way to a search of topological quantities in non-equilibrium dynamics.

[1] N. Fläschner, et al., Science 352, 1091 (2016)
[2] N. Fläschner, et al., arXiv:1608.05616 (2016)

Q 52.2 Thu 14:45 P 204

Synthetic Creutz-Hubbard Model: Interacting Topological Insulators with Ultracold Atoms — Johannes Jünemann[1,2], Angelo Piga[3], Shi-Ju Ran[3], Maciej Lewenstein[3,4], •Matteo Rizzi[1], and Alejandro Bermudez[5,6] — [1]Johannes Gutenberg-Universität, Mainz (Germany) — [2]MAINZ - Graduate School Materials Science in Mainz (Germany) — [3]ICFO-Institut de Ciencies Fotoniques, Castelldefels (Spain) — [4]ICREA-Institució Catalana de Recerca i Estudis Avançats, Barcelona (Spain) — [5]Swansea University (UK) — [6]Instituto de Física Fundamental, IFF-CSIC, Madrid (Spain)

Understanding the robustness of topological phases of matter in the presence of strong interactions, and synthesising novel strongly-correlated topological materials, lie among the most important challenges of modern theoretical and experimental physics. Here we present a complete theoretical analysis of the Creutz-Hubbard ladder, a paradigmatic model that provides a neat playground to address these challenges. We put special attention to the competition of exotic topological phases and orbital quantum magnetism in the regime of strong interactions and identify the universality class of the different phase transitions. These results are furthermore confirmed and extended by extensive numerical simulations and analysis of the entanglement properties. Moreover, we propose how to experimentally realize this model and test its phase diagram in a synthetic ladder, made of two internal states of ultracold fermionic atoms in a one-dimensional optical lattice. Our work paves the way towards quantum simulators of interacting topological insulators with cold atoms.

Q 52.3 Thu 15:00 P 204

One dimensional massless Lorentz Invariant Systems on Ring with magnetic Flux — •Manon Bischoff[1], Johannes Jünemann[1], Matteo Rizzi[1], and Marco Polini[2] — [1]JGU Mainz — [2]IIT Genua

The persistent current response of one dimensional (1D) electrons on a ring pierced by a magnetic flux has been longly studied in solid state setups. Little attention has been however devoted to systems with Dirac-cone dispersion at the Fermi-level, and the few available results are focused on the non-interacting case. Here we investigate the scaling of the current and its response with respect to system-size and interaction-strength in a (quasi-)1D Creutz ladder model with Hubbard interactions, as realisable in cold atomic setups. We present both analytical results based on bosonization and numerical results obtained using so-called binary tree-tensor networks. The current response behaves very similarly to the Drude weight of the 1D Hubbard model: it vanishes at exactly half-filling as soon as interactions are turned on (thus testifying a gap opening), while it stays finite and positive away from that (the system stays in the Luttinger liquid regime). This is instead in contrast with two dimensional massless Lorentz invariant systems, where the magnetic susceptibility (also the persistent current response to a piercing flux) away from half-filling is vanishing in the free case and interactions can induce a net negative response.

Q 52.4 Thu 15:15 P 204

Signatures of topological phases in ultracold fermionic ladders — •Andreas Haller[1], Leonardo Mazza[2], Matteo Rizzi[1], and Michele Burrello[3] — [1]Institute of Physics, Johannes Gutenberg University, 55099 Mainz, Germany — [2]Département de Physique, Ecole Normale Supérieur, 75005 Paris, France — [3]Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

Inspired by the recent experimental advances in the study of ultracold atoms trapped in optical lattices, we consider models of ultracold fermions hopping in ladder geometries and subject to artificial magnetic fluxes.

In the presence and absence of interactions, we investigate the thermodynamic phases that can emerge in these simple, quasi-one-dimensional setups.

By applying the concept of resonances in chiral currents, we find a topological order parameter, distinguishing between trivial and quantum Hall (QH) phases.

We aim for evidence about fractional QH phases in ladders with short-range repulsive interactions: For both nearest and next-to-nearest neighbor interactions, tensor network simulations show not only the appearance of the expected $\nu = 1/3$ Laughlin-like states, but also of an exotic $\nu = 1/2$ phase.

Q 52.5 Thu 15:30 P 204

Topological order in finite-temperature Gaussian fermionic systems — •Lukas Wawer, Dominik Linzner, and Michael Fleischhauer — Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern,

Deutschland

Since their discovery, topological states of matter have been praised for their fascinating and potentially useful properties as protected edge states or anyonic excitations. However, these features seem to vanish at finite temperature. Exploiting the equivalence of Zak (or Berry) phase and polarization we can classify topological order in finite-temperature systems by means of the many body polarization [1]. We show that topological order defined in this way survives at any finite temperature in Gaussian fermionic systems. On the one hand we consider a 1D model for symmetry protected topological order (Su-Schrieffer-Heeger model) and find that there is a quantized winding of the polarization for closed paths in parameter space. On the other hand we study a 2D model (Hofstadter-Hubbard model) with intrinsic topology and show that there is an integer change of polarization at any finite temperature if we go through the Brillouin zone. This change of polarization can be identified as the counterpart of the Chern number in closed 2D models. [1] D. Linzner, L. Wawer, F. Grusdt, and M. Fleischhauer, Phys. Rev. B 94, 201105(R) (2016)

Q 52.6 Thu 15:45 P 204

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 52.7 Thu 16:00 P 204

Measurement of the merging transition of Dirac points in a tunable optical lattice — •Matthias Tarnowski[1,3], Marlon Nuske[2], Nick Fläschner[1,3], Benno Rem[1,3], Dominik Vogel[1], Klaus Sengstock[1,2,3], Ludwig Mathey[1,2,3], and Christof Weitenberg[1,3] — [1]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Topological defects, such as Dirac points in graphene, and their resulting Berry phases play an important role, e.g. for the electronic dynamics in solid state crystals. Tunable quantum gas systems in optical lattices allow for deep and new insights into topological properties of quantum many-body systems. Here we discuss the experimental observation of the so-called merging transition of Dirac points in a tunable hexagonal optical lattice in a boron nitride configuration. We have developed a new method to fully map out the positions of the topological defects in a two-band model. Our measurements illustrate that topological defects are robust under change of lattice parameters and can only be destroyed by annihilation of two vortices with opposite winding.

Q 52.8 Thu 16:15 P 204

High-Precision Spectroscopy of Ultracold Fermions in a Honeycomb Lattice — •Nick Fläschner[1,2], Benno S. Rem[1,2], Matthias Tarnowski[1,2], Dominik Vogel[1], Christof Weitenberg[1,2], and Klaus Sengstock[1,2,3] — [1]ILP - Institut für Laserphysik, Hamburg, Deutschland — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Deutschland — [3]ZOQ - Zentrum für Optische Quantentechnologien, Hamburg, Deutschland

Ultracold atoms in optical lattices with tunable geometry [1-4] can be employed to emulate various solid-state systems. For the understanding of such complex quantum systems, it is desirable to develop versatile spectroscopy methods. Here we demonstrate a high-precision multi-band spectroscopy in a honeycomb lattice using ultracold fermionic atoms. We determine both the fully momentum-resolved energy spectrum and the excitation probabilities, which reflect the symmetry of the eigenstates and e.g. the Dirac cones in the system. Our results provide an ideal starting point for the investigation of interacting systems.

[1] Becker et al., New J. Phys. 12, 065025 (2010)
[2] Soltan-Panahi et al., Nat. Phys. 7, 434-440 (2011)
[2] Taruell et al., Nature 483, 302-305 (2012)
[3] Fläschner/Rem et al., Science 352, 1091-1094 (2016)

Q 52.9 Thu 16:30 P 204

Exact Quantum Field Mappings Between Different Experiments on Quantum Gases — •Etienne Wamba[1,2], Axel Pelster[1], and James R. Anglin[1] — [1]State Research Center OPTIMAS and Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]International Center for Theoretical Physics, 34151 Trieste, Italy

Experiments on trapped quantum gases can probe challenging regimes of quantum many-body dynamics, where strong interactions or nonequilibrium states prevent exact solutions. Here we present a different kind of exact result, which applies even in the absence of actual solutions: a class of space-time mappings of different experiments onto each other [1]. Since our result is an identity relating second-quantized field operators in the Heisenberg picture of quantum mechanics, it is extremely general; it applies to arbitrary measurements on any mixtures of Bose or Fermi gases, in arbitrary initial states. It represents a strong prediction of quantum field theory which can be tested in current laboratories, and whose practical applications include perfect simulation of interesting experiments with other experiments which may be easier to perform.

[1] Phys. Rev. A **94**, 043628 (2016)

Q 53: Poster: Quantum Optics and Photonics III

Time: Thursday 17:00–19:00 Location: P OGs

Q 53.1 Thu 17:00 P OGs

Topological phases and dynamics of topological excitations in the one-dimensional super-lattice Bose Hubbard model with non-local interactions — •Rui Li, Dominik Linzner, and Michael Fleischhauer — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany

We investigate Mott insulating phases of the one-dimensional super-lattice Bose-Hubbard model (SL-BHM) with local and next-nearest-neighbor interactions at fractional fillings. In an infinite system the ground state of this model is degenerate and the different ground states can be distinguished by a topological quantum number. In a finite system with periodic boundary conditions, incommensurate with the filling of the bulk ground state, domain walls appear, which are topological excitations. We calculate the phase diagram of the extended SL-BHM and analyze the dynamics of such topological excitations using time-evolving block decimation (TEBD) simulations. We discuss potential applications of the topological excitations for robust information transport.

Q 53.2 Thu 17:00 P OGs

Absence of topological order in open non-interacting bosonic systems — •Christopher Mink, Lukas Wawer, Dominik Linzner, and Michael Fleischhauer — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany

In recent years, systems with topological order have attracted interest, as they have been associated with exotic, strongly correlated quantum states and can possess protected edge states. However, these fascinating features are not robust against dissipation. In previous investigations [1], we found that the winding of the many-body polarization remains a viable topological invariant for open quantum systems. Waveguide technology can be used to realize non-interacting bosonic systems with topological band structure [2,3]. Thus it is instructive to study the topology of these systems in particular. By characterizing steady states using correlations, we can express the polarization for non-interacting, i.e. Gaussian fermionic and bosonic systems in terms of the one-body correlation matrix. We show that non-interacting fermionic systems can in general exhibit a non-trivial winding of polarization, while the same does not hold true for bosonic systems.

[1] D. Linzner et. al., Phys. Rev. B 94, 201105(R) (2016).
[2] M. Hafezi et. al., Nat. Photonics 7, 1001 (2013).
[3] M. C. Rechtsman et. al., Nature (London) 496, 196 (2013).

Q 53.3 Thu 17:00 P OGs

Towards a hybrid quantum system: ultrafast ionization of a Bose-Einstein condensate — Tobias Kroker[2,3], •Steffen Pehmöller[2], Bernhard Ruff[2,3], Juliette Simonet[1,3], Philipp Wessels[1,3], Markus Drescher[2,3], and Klaus Sengstock[1,3] — [1]Zentrum für Optische Quantentechnologien, Hamburg, Germany — [2]Institut für Experimentalphysik, Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

The combination of ultracold atomic systems and ultrafast laser pulses promises insight into the coherence properties of macroscopic dissipative quantum systems and enables the preparation of hybrid quantum systems through local ionization of atoms in strong laser fields. Here, we report on our progress in setting up a quantum gas machine where the ultracold gases are optically transported into the focal region of the femtosecond laser beam. Our setup aims for counting ions while detecting the impact pattern of the photoelectrons. Furthermore, we report on quantitative studies of strong-field ionization of a Bose-Einstein condensate via loss measurements and pulsed momentum transfer due to dipole forces.

Q 53.4 Thu 17:00 P OGs

Magnetic field control for new periodic driving schemes in optical lattices — •Tobias Klafka, Alexander Ilin, Julius Seeger, Christoph Ölschläger, Juliette Simonet, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg

For quantum gas experiments, an improved control over the magnetic field allows implementing new driving schemes for Floquet engineering. In particular, this becomes important when internal atomic states are coherently coupled. In spin-dependent hexagonal lattices, magnetic fields can be used to open the Dirac cones in a controlled manner.

We report on the setup of an active compensation for stray magnetic fields which can be implemented in nearly any quantum gas experiment. DC and AC magnetic fields can be attenuated below 1mG for frequencies up to 1kHz. The magnetic field stability has been characterized using Ramsey spectroscopy of a Bose-Einstein condensate.

Q 53.5 Thu 17:00 P OGs

Observation of parametric resonances in 1D shaken optical lattices — •Jakob Näger[1,2], Karen Wintersperger[1,2], Martin Reitter[1,2], Ulrich Schneider[3], and Immanuel Bloch[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstr. 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching — [3]University of Cambridge, Cambridge, UK

We study a BEC of 39K with tunable interactions in a shaken 1D optical lattice. Due to the interplay between the external drive and interactions dynamical instabilities arise [1]. The short-time dynamics can be captured by parametric resonances within Bogoliubov theory, which should lead to a fast decay of the BEC. At long times, the behavior will be dominated by collision processes described by a Fermi's Golden rule approach that slow down the decay. Varying the shaking parameters and interactions, we observe the transition between the two heating regimes. Moreover, we can identify the onset of the parametric instabilities at short times by analysing the 2D quasimomentum distribution of the excited atoms.

[1] S. Lellouch et al., arXiv:1610.02972v1 (2016)

Q 53.6 Thu 17:00 P OGs

Cavity-induced supersolidity and its elementary excitations — •Philip Zupancic, Julian Leonard, Andrea Morales, Tilman Esslinger, and Tobias Donner — ETH Zürich, Zürich, Schweiz

We report on the first coupling of a Bose-Einstein condensate to two optical cavities. The combination of self-organisation processes with discrete symmetries in each cavity gives rise to one enhanced, continuous symmetry. When this U(1) symmetry is broken, a supersolid emerges – a state of matter that is both crystalline and superfluid. We provide evidence for both key properties. The light fields leaking from the cavities allow real-time observation of crystal movements. We investigate the mode spectrum of our supersolid phase and present measurements on the mode softening at the phase transition and the paired Nambu-Goldstone/amplitude modes inside the phase.

Q 53.7 Thu 17:00 P OGs

Towards Raman coupling induced 2D spin-orbit coupling for ^{87}Rb — •Sebastian Bode, Felix Kösel, Holger Ahlers, Naceur Gaaloul, and Ernst M. Rasel — IQ Universität Hannover

Presentation of the experimental steps towards synthesizing 2D Spin-orbit-coupling in a spinor Rubidium Bose-Einstein condensate.

Cyclically coupling the hyperfine Zeeman states via Raman transitions, will create an effective gauge field [1], resembling the ones in spintronic systems [2]. Such artificial interactions offer rich ground state dynamics and allow the realization of advanced solid state simulators with non-Abelian character in a versatile cold-atom system.

[1] L. Huang et al., Nature Physics 12, 540-544 (2016).
[2] H. C. Koo et al., Science 325, 1515 (2009).

Q 53.8 Thu 17:00 P OGs

Deterministic Loading of Arbitrary Potentials — •Romain Müller, Robert Heck, Otto Eliasson, Jens Laustsen, Aske Thorsen, Jan Arlt, and Jacob Sherson — Aarhus Universitet, Denmark

The ability to detect and manipulate single atoms in optical lattices [1,2,3] and the deterministic loading of atoms into tweezers [4,5,6] has opened the doors for novel types of experiments.

In this poster we present our route to combine single atom control in optical lattices and deterministic loading into smooth or periodic arbitrary potentials using multiple digital micromirror devices (DMD) in combination with a quantum gas microscope. This should allow to simulate various quantum phenomena and to study the dynamics in different systems, like in ring lattices. Due to the high speed of the DMDs (10kHz frame rate), they will also allow incorporating the players' results of our game 'Quantum moves' to test the quantum speed limit [7].

[1] W. Bakr et al., Nature 462, 74-77
[2] J. Sherson et al., Nature 467, 68-72
[3] C. Weitenberg et al., Nature 471, 319-324
[4] A. Kaufman et al., Nature 527, 208-211
[5] D. Barredo et al., Science Vol. 354, Issue 6315, pp. 1021-1023
[6] M. Endres et al, Science Vol. 354, Issue 6315, pp. 1024-1027
[7] J. Sørensen et al, Nature 532, 210-213

Q 53.9 Thu 17:00 P OGs

Non-equilibium BCS state in a Fermi gas — •Alexandra Behrle, Timothy Harrison, Martin Link, Andreas Kell, Kuiyi Gao, and Michael Köhl — Physikalisches Institut, University of Bonn, 53115 Bonn, Germany

Ultracold Fermi gases with tunable interactions have been widely used to investigate the BEC-BCS crossover in the last decade and superfluidity of Fermi gases with different interactions have shown a variety of rich physics. So far, the focus of research has mainly been on the equilibrium state of an attractive gas of cooper pairs. Non-equilibrium coherent dynamics of the BCS state was proposed for studying collective modes, pair formation and excitations in superconductivity, however, experimental realization has been hindered by the difficulty of performing fast enough changes in to the system. In this talk, we will show our efforts in preparing and detecting a non-equilibrium BCS-superfluid of fermionic 6Li atoms. We focus on the coherent dynamics with fast modulation and quenched interactions using fast ramps across the Feshbach resonance.

Q 53.10 Thu 17:00 P OGs

Spin and Charge Correlation Measurements in the 2D Hubbard Model — Jan Drewes[1], Luke Miller[1,2], Eugenio Cocchi[1,2], Chun Fai Chan[1], Nicola Wurz[1], •Marcell Gall[1], Daniel Pertot[1], Ferdinand Brennecke[1], and Michael Köhl[1] — [1]Physikalisches Institut, University of Bonn, Wegelerstrasse 8, 53115 Bonn, Germany — [2]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE, United Kingdom

We experimentally study the emergence of correlations in an ultracold, fermionic 2D lattice system, representing a realisation of the Hubbard model. Our ability to precisely tune the system parameters over a large range and the possibility to simultaneously detect the density distribution of both spin components in-situ enables us to examine the emergence of density and spin correlations as a function of doping interaction strength and temperature. In addition we gain from the measurement of the equation of state insight into the full thermodynamics of the 2D Hubbard model. To improve our preparation and detection capabilities, we use a spin spiral technique which allows us to detect the spin structure factor at arbitrary wave vectors. Further we employ a spatial light modulator to reshape the underlying trapping potential of the optical lattice to realize the homogeneous Hubbard model and reach lower temperatures by redistributing entropy between different spatial regions.

Q 53.11 Thu 17:00 P OGs

BEC of ^{41}K in a Fermi Sea of ^{6}Li — Rianne S. Lous[1,2], Isabella Fritsche[1,2], •Fabian Lehmann[1,2], Michael Jag[1,2], Emil Kirilov[1,2], Bo Huang[1], and Rudolf Grimm[1,2] — [1]IQOQI, Austrian Academy of Science, Innsbruck, Austria — [2]Inst. for Experimental Physics, University of Innsbruck, Innsbruck, Austria

We report on the production of a double-degenerate Fermi-Bose mixture of ^{6}Li and ^{41}K. In our experimental sequence the potassium atoms are sympathetically cooled by the lithium atoms, which are evaporatively cooled in an optical dipole trap. We obtain 10^4 ^{41}K atoms with a BEC fraction close to 1 and a $T/T_F \approx 0.05$ with 10^5 ^{6}Li atoms in each spin state. To measure the temperature of our fermionic sample we use the ^{41}K BEC as a tool for thermometry. As the system is in thermal equilibrium we evaluate the condensed fraction of our ^{41}K atoms and extract the temperature of the atoms. To investigate the properties of the ^{6}Li-^{41}K mixture near the inter-species Feshbach resonance at 335.8 G we use another scheme of evaporation around 300 G which enables us to achieve similar temperatures. We explore both the repulsive side and attractive side of the Feshbach resonance and observe phase separation for strong repulsive interactions and collapse for attractive interactions. This work is supported by the Austrian Science Fund FWF within the SFB FoQuS.

Q 53.12 Thu 17:00 P OGs

Probing Many-body physics with an ultra-narrow clock transition in an Ytterbium quantum gas — •Bodhaditya Santra[1], Benjamin Abeln[1], Bastian Hundt[1], André Kochanke[1], Thomas Ponath[1], Anna Skottke[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

During the last decade ultracold fermionic alkaline earth quantum gas attracted a lot of attention due to their unique properties such as long-lived meta-stable state, an ultra-narrow optical clock transition, SU(N) symmetric interactions as well as the existence of an interorbital Feshbach resonance. In particular fermionic Yb quantum gas allow for quantum simulation of lattice systems with orbital degrees of freedom, like the Kugel-Khomskii model or the Kondo lattice model (KLM).

We will present recent progress of the Hamburg Yb experiment towards realizing the KLM and correlated KLM, including measurements on spin polarized as well as on interacting Fermi gases with an improved clock laser setup.

This work is supported by the DFG within the SFB 925 and the Marie Curie Initial Training Network QTea.

Q 53.13 Thu 17:00 P OGs

Local control of transport in an atomic quantum wire: from one scanning gate to a finite size lattice — •Samuel Häusler[1], Martin Lebrat[1], Dominik Husmann[1], Laura Corman[1], Sebastian Krinner[1], Shuta Nakajima[2], Jean-Philippe Brantut[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland — [2]Department of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan

Building on the holographic shaping of optical potentials and a high-resolution microscope, we demonstrate the local control of fermionic lithium atoms flowing through a one-dimensional structure. We first image the transport through a quantum wire, in a way similar to the scanning gate technique applied to solid state devices. By scanning the position of a sharp, repulsive optical gate over the wire and measuring the subsequent variations of conductance, we spatially map the transport at a resolution close to the transverse wavefunction inside the wire. The control of the gate at the scale of the Fermi wavelength makes it sensitive to quantum tunnelling. Furthermore, our knowledge of the optical potential allows a direct comparison of the experimental maps with a numerical and an analytical model for non-interacting particles.

The flexibility offered by our setup makes it relatively simple to imprint more complex structures. By projecting several consecutive scatterers, a lattice of variable length can be built inside the quantum wire. This opens the path to study metal-insulator physics with strong attractive interactions.

Q 53.14 Thu 17:00 P OGs

Interacting Anyons in a One-Dimensional Optical Lattice — •Martin Bonkhoff, Kevin Jägering, Sebastian Eggert, and Axel Pelster — State Research Center OPTIMAS and Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We analyze in detail the properties of the one-dimensional Anyon-Hubbard model, which can be mapped to a corresponding Bose-Hubbard model with a density-dependent Peierls phase via a generalized Jordan-Wigner transformation [1]. At first we extend the modified version of the classical Gutzwiller-mean-field ansatz of Ref. [2] in order to obtain the pair-correlation function for both the bosonic and the anyonic system. A comparison of the resulting quasi-momentum distributions with high-precision DMRG calculations reveals in general a parity breaking, which is due to anyonic statistics. Afterwards, we determine how the boundary of the superfluid-Mott quantum phase transition changes with the statistical parameter. We find in accordance with Ref. [1] that the statistical interaction has the tendency to destroy superfluid coherence.

[1] T. Keilmann, S. Lanzmich, L. McCulloch, and M. Roncaglia, Nat. Commun. **2**, 361 (2011)

[2] G. Tang, S. Eggert, and A. Pelster, New J. Phys. **17**, 123016 (2015)

Q 53.15 Thu 17:00 P OGs

Creating topological interfaces and detecting chiral edge modes in a two-dimensional optical lattice — •Frederik Görg[1], Nathan Goldman[2], Gregor Jotzu[1], Michael Messer[1], Kilian Sandholzer[1], Rémi Desbuquois[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, Zurich, Switzerland — [2]CENOLI, Université Libre de Bruxelles, Brussels, Belgium

The appearance of topological properties in lattice systems caused by a non-trivial topological band structure in the bulk is closely related to the existence of chiral edge modes via the bulk-edge correspondence. These edge states appear at the interface of two spatial regions with a distinct topology, which for example naturally arise at the boundaries of a sample surrounded by vacuum. In cold atom systems, these edge modes are difficult to detect, since the underlying harmonic trapping potential does not feature sharp boundaries. Therefore, we propose a different method to design topological interfaces within the bulk of the system. We illustrate this scheme by an optical lattice realization of the Haldane model, where a spatially varying lattice beam leads to the appearance of distinct topological phases in separated regions of space. The versatility of the method allows to tune the position, the localization length and the chirality of the edge modes. We numerically study the propagation of wave packets in such a system and demonstrate the feasibility to experimentally detect chiral edge states. Finally, we show that the edge modes, unlike the bulk states, are topologically protected against the effects of disorder, which makes a random potential a powerful tool to detect edge states in cold atom setups.

Q 53.16 Thu 17:00 P OGs

Transport dynamics in optical lattices with flux — •Ana Hudomal[1], Ivana Vasić[1], Walter Hofstetter[2], and Antun Balaž[1] — [1]Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, Frankfurt am Main, Germany

Recent cold atom experiments have realized artificial gauge fields in periodically modulated optical lattices [1,2]. We study the dynamics of atomic clouds in these systems by performing numerical simulations using the full time-dependent Hamiltonian and comparing these results to the semiclassical approximation. Under constant external force, atoms in optical lattices with flux exhibit an anomalous velocity in the transverse direction. We investigate in detail how this transverse drift is related to the Berry curvature and Chern number, taking into account realistic experimental conditions.

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

Q 53.17 Thu 17:00 P OGs

Towards the investigation of collective scattering in nanofiber-trapped atomic ensembles — •Adarsh S. Prasad, Jakob Hinney, Samuel Rind, Philipp Schneeweiss, Jürgen Volz, Christoph Clausen, and Arno Rauschenbeutel — TU Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria

We realize an efficient optical interface between guided light and laser-cooled atoms which are arranged in two linear arrays in a two-color evanescent-field dipole trap created around an optical nanofiber [1]. In this configuration, the probability of a nanofiber-guided photon being absorbed and then re-emitted into free space by a trapped atom is as high as 10%. For a periodic array of atoms, interference of the fields scattered by different atoms result in a collective emission into a cone with a well-defined angle with respect to the fiber axis. We plan to study this collective emission and its dependence on various experimental parameters. The next step will be to adjust the periodicity of the atomic array to fulfill the Bragg condition such that fiber-guided light is strongly back-reflected [2]. Here, the interaction between the atomic array and the fiber-guided light depends strongly on the polarization of the light field. In particular, light that is polarized in (orthogonal to) the plane of atoms will be weakly (strongly) reflected. We want to implement such highly reflecting atomic arrays, which could then be used to implement cavity quantum electrodynamics experiments in which the resonator itself is made of quantum emitters.

[1] E. Vetsch et al., Phys. Rev. Lett. 104, 203603 (2010).
[2] Fam Le Kien et. al., Phys. Rev. A 90, 063816 (2014).

Q 53.18 Thu 17:00 P OGs

Setup of a new micro-structured linear Paul trap with integrated solenoids and reduced axial micromotion — •H. Siebeneich, D. Kaufmann, T. Gloger, P. Kaufmann, M. Johanning, and ch. Wunderlich — Department Physik, Universität Siegen, 57068 Siegen, Germany

We present the status of a new 3d segmented ion trap setup with integrated solenoids, in which an improved design allows for a substantial reduction of axial micromotion and for an increased magnetic gradients. Our trap consists of three layers of gold plated alumina, where the segmented outer layers provide the trapping potentials [1], and the middle layer contains solenoids that are used to create a magnetic field gradient [2]. The gradient gives rise to coupling between the ions' internal and motional states. 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 thick film interface has been improved by replacing previously used Ag-Pd layers by Au layers which reduced their resistivity by a factor of eight. The previously high resistivity used to be a a bottleneck for achieving high solenoid currents and thus a magnetic gradient. The shape of the solenoids was redesigned, leading to an expected reduction of axial micromotion by four orders of magnitudes.

[1] S.A. Schulz et al.: Sideband cooling and coherent dynamics in a microchip multi-segmented ion trap, New Journal of Physics, Volume 10, April 2008 [2] D. Kaufmann et al.: Thick-film technology for ultra high vacuum interfaces of micro-structured traps, Appl Phys B (2012) 107:935-943

Q 53.19 Thu 17:00 P OGs

Design and construction of a Perpetual Atom Laser Machine — •Chun-Chia Chen, Shayne Bennetts, Benjamin Pasquiou, and Florian Schreck — Institute of Physics, University of Amsterdam, Amsterdam, The Netherlands

We have developed a machine aimed at producing a perpetual atom laser, a long standing goal within atomic physics. Continuous production of Bose-Einstein condensate (BEC) or an atom laser requires two incompatible cooling processes, laser cooling a gas sample, then cooling evaporatively until degeneracy is reached. In order to produce a perpetual output these stages take place simultaneously in different parts of our machine. To protect the condensate from scattered photon heating we use a combination of physical separation, baffles and a "transparency" beam. Our machine has now demonstrated a perpetual MOT of 2×10^9 ^{88}Sr atoms with temperatures as low as 20μK on a 7.4-kHz wide laser cooling transition with a continuous loading rate of 7×10^8 atoms/s. Using a different set of parameters and location we have also demonstrated a perpetual MOT of 2×10^8 ^{88}Sr at 2μK with a loading rate of 9×10^7 atoms/s which we have successfully loaded into a dipole trap. By switching to the 0.5% abundance ^{84}Sr isotope we are able to evaporate to BECs of 3×10^5 ^{84}Sr atoms. Critically, for the second location we have validated the effectiveness of our architecture in protecting a BEC from scattered broad-linewidth laser cooling light, which is used in the first cooling stages. We will describe our design and the performance demonstrated so far.

Q 53.20 Thu 17:00 P OGs

Optical trapping of neutral mercury — •Holger John and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Schlossgartenstraße 7, 64289 Darmstadt

Laser-cooled mercury constitutes an interesting starting point for various experiments, in particular in light of the existence of bosonic and fermionic isotopes. On the one hand the fermionic isotopes could be used to develop a new time standard based on an optical lattice clock employing the $^1S_0$ - $^3P_0$ transition. Another interesting venue is the formation of ultra cold Hg-dimers employing photo-association and achieving vibrational cooling by employing a special scheme.

The laser system is based on an interference-filter stabilized external cavity diode laser with excellent spectral properties combined with a home built non-cryogenic fiber amplifier for the 1015nm fundamental wavelength with a slope-efficiency of more than 35 % delivering up to 4W of pump limited output power. The fundamental wavelength is frequency doubled twice to reach the cooling transition at 253.7 nm. The challenging requirements meeting the natural linewidth of 1.27 MHz are mastered by use of a ULE reference resonator.

After integrating a 2D-MOT as an atom source to the vacuum system the first measurements of ultra-cold atoms with the new laser system will be reported.

Q 53.21 Thu 17:00 P OGs

Diffusion of Single Atoms in Bath — •Daniel Adam, Farina Kindermann, Tobias Lausch, Daniel Mayer, Felix Schmidt, Steve Haupt, Michael Hohmann, Nicolas Spethmann, and Artur Widera — TU Kaiserslautern, Department of Physics, Kaiserslautern, Germany

Diffusion is an essential phenomenon occurring in various systems such as biological cells, traffic models or stock markets. While most systems are well described by standard Brownian motion, anomalous diffusion can lead to markedly different dynamical properties.

Experimentally, we study the diffusion of individual atoms illuminated by near-resonant light and trapped in a periodic potential. All relevant parameters such as damping coefficient and potential hight can be controlled in order to realize different diffusive regimes.

We explore the amount of information contained in the Kramers rate, i. e. the rate at which a diffusing atom can escape from a potential well. Furthermore we exploit the excellent control over the optical trapping potential and study the diffusion of the atom in a time-varying periodic trap, complemented by numerical simulations of the dynamics.

Q 53.22 Thu 17:00 P OGs

Kinetic Monte Carlo simulation of percolation in driven-dissipative Rydberg gases — •Stephan Helmrich, Philipp Fabritius, Graham Lochead, and Shannon Whitlock — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Directed percolation is perhaps the most prominent example of a unique class of phenomena which exhibit genuine non-equilibrium phase transitions and non-trivial critical behaviour. We explore whether highly tunable gases of ultracold atoms excited to long-range interacting Rydberg states can serve as a clean experimental realisation of percolation phenomena in two and three dimensions. The mechanism investigated is the cooperative excitation of Rydberg atoms triggered when the excitation laser is resonant for atoms within a characteristic distance of another Rydberg atom (facilitated excitation). To simulate the dynamics of this system we use a kinetic Monte Carlo algorithm which is able to reproduce many of the experimental features of laser excited Rydberg gases. We investigate the scaling behavior for the fraction of Rydberg excitations (active sites) and their spatial correlations, both at steady-state and following a sudden quench from the inactive to the active phase. Based on these observations we can address whether percolation can realistically be studied in driven-dissipative systems of ultracold Rydberg atoms.

Q 53.23 Thu 17:00 P OGs

Simulation of many-body spin dynamics using Rydberg atoms — •Renato Ferracini Alves, Miguel Ferreira-Cao, Vladislav Gavryusev, Sebastian Geier, Andre Salzinger, Gerhard Zürn, Adrien Signoles, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Due to its long range interactions, ultracold Rydberg gases are a suitable platform for analog quantum simulation of many-body spin dynamics. This allows us to investigate, in a controlled environment, physical phenomena related to practical but less tunable systems, such as quantum magnetism in condensed matter materials. In our experiment we realize these spin models, by mapping two strongly interacting Rydberg states to two spin 1/2 states ($|n,l\rangle \rightarrow |\downarrow\rangle$ and $|n',l'\rangle \rightarrow |\uparrow\rangle$). We will present preliminary results of the characterization of this microwave-driven spin dynamics, through global variables, using a phase-controlled driving field. We measured a density-dependent damping of the magnetization, that we attribute to interactions, and observe that its dynamics cannot be fully explained by mean field approximations. Techniques such as Ramsey interrogation, spin locking and quantum state tomography, enabled by the phase control of the driving field, are used to characterize this magnetization dynamics in more detail.

Q 53.24 Thu 17:00 P OGs

Noise resistant coupling between Rydberg atoms and a superconducting cavity via dipole-dipole interactions — •Daniel Viscor[1], Wildan Abdussalam[1], József Fortágh[2], Antoine Browaeys[3], Thierry Lahaye[3], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany — [2]Physikalisches Institut der Universitat Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [3]Laboratoire Charles Fabry, Institut d'Optique, CNRS, Univ Paris Sud 11, 2 Avenue Augustin Fresnel, F-91127 Palaiseau Cedex, France

We theoretically study the coherent exchange of a single photon between a superconducting microwave cavity and a lattice of strongly interacting Rydberg atoms in the presence of local electric field fluctuations plaguing the cavity surface. We show that despite the increased sensitivity of Rydberg states to electric fields, the Rydberg dipole-dipole interaction can be used to protect the system against the dephasing induced by the spurious fields. Using realistic noise models we show that compared to the case with non-interacting atoms, our system exhibits longer coherence lifetimes and larger retrieval efficiency of the photon after storing into the atoms.

Q 53.25 Thu 17:00 P OGs

Ultra cold dipolar ^{23}Na^{40}K molecules in Garching — Frauke Seesselberg[1], •Xin-Yu Luo[1], Nikolaus W. Buchheim[1], Zhenkai Lu[1], Immanuel Bloch[1,2], and Christoph Gohle[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany

Ultracold quantum gases with long-range dipolar interactions promise exciting new possibilities for quantum simulation of strongly interacting many-body systems like fractional Mott insulators and supersolid phases. Our experimental apparatus is capable of creating ultracold mixtures of sodium and potassium. Recently we succeeded to produce ultracold ^{23}Na^{40}K molecules in their rotational, vibrational and electronic ground state.

We discuss the experimental apparatus and experimental steps required to achieve this. In particular we investigate the Feshbach molecules creation from the ultracold atomic sample using RF-association near the 89G interspecies Feshbach resonance, efficient ground state transfer to the rovibronic molecular ground state using a stimulated Raman adiabatic passage employing the $\mathrm{d}^3\Pi(v=5, J=1, \Omega=1)$ intermediate state which mixes with the $\mathrm{D}^1\Pi$ electronic state via spin orbit interaction and discuss the properties of the ground state such as it's lifetime and polarizability.

Q 53.26 Thu 17:00 P OGs

Optical transport of ultracold atoms for the production of groundstate RbYb — •Tobias Franzen, Bastian Pollklesener, Fabian Türck, Richarda Niemann, 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 53.27 Thu 17:00 P OGs

Cavity-controlled chemical reactions of ultracold atoms — Tobias Kampschulte[1], Limei Wang[1], •Guangming Liu[1], 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". Furthermore, we want to use the cavity for direct optical detection of ultracold molecules.

In the experiment, we are implementing an optical microcavity into an existing Rb 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 53.28 Thu 17:00 P OGs

Optical formation of weakly-bound, fermionic ^{87}Rb^{87}Sr molecules — •Alessio Ciamei, Vincent Barbé, Benjamin Pasquiou, and Florian Schreck — Institute of Physics, University of Amsterdam, Amsterdam, The Netherlands

We are pursuing the creation of ultracold RbSr ground-state molecules. In contrast to ultracold ground-state molecules created so far, RbSr molecules do not only have a large electric dipole moment (1.5 Debye), but also an unpaired electron. These properties give us a larger parameter space to tune interactions by applying electromagnetic fields, providing us with a path towards a quantum gas of ground-state molecules and quantum simulation. We present the creation of a ^{84}Sr-^{87}Rb Mott insulator, which is our starting point for molecule association using the Sr $^1S_0 \rightarrow {}^3P_1$ transition. We find that only very weak optical transitions to molecular states exist in this isotopic mixture, hindering us from coherently creating molecules. Using mass-scaling, our spectroscopy data points to a promising molecule association path in the ^{87}Sr-^{87}Rb mixture, which we indeed were recently able to find experimentally. Finally, we present a scheme for the efficient and coherent creation of long-lived, ultracold Sr_2 molecules, which exploits a light-shift compensation method. Together, our spectroscopy data for the ^{87}Sr-^{87}Rb mixture and our light-shift compensation technique, identify a path towards weakly-bound ^{87}Rb^{87}Sr molecules.

Q 53.29 Thu 17:00 P OGs

ATLIX - probing the wave nature of antiprotons — •Simon Müller[1], Andrea Demetrio[1], Pierre Lansonneur[2], Patrick Nedelec[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 wave behavior of particles is a well accepted and experimentally verified phenomenon. It has been shown for several different species, ranging from electrons to very large organic molecules. Antimatter is expected to show the same behaviour, but experiments on the topic are still in progress. Here we present the current developments in the ATLIX project (Antiproton Talbot-Lau Interferometry eXperiment) where the defined goal is the realization of an antiproton interferometer at the CERN Antiproton Decelerator facility (AD).

The interferometer consists of three material gratings with nano-metric periodicity and is planned to be suitable for antiprotons with energy up to 10 keV. A first prototype of the experiment is being carried out in Heidelberg with protons and neutral hydrogen in the 500 eV - 2 keV range. The results of these preliminary experiments will be presented.

Q 53.30 Thu 17:00 P OGs

Realistic simulation of expansion dynamics of an ultracold gas for atom interferometry — •Srihari Srinivasan and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt, Hochschulstraße 4a, 64289 Darmstadt

The versatility of Bose-Einstein Condensates (BEC) in experiments has given rise to an entire genre of topics ranging from quantum optics and condensed matter physics to quantum simulators and sensors. The QUANTUS collaboration [1] aims to use atom interferometry with an ultracold ^{87}Rb gas in a compact, rugged module that is either dropped or catapulted inside a vacuum drop tower at ZARM in Bremen [2]. The experiment aims to use atom interferometry in micro-gravity under free fall to test Einstein's Equivalence Principle.

Expansion dynamics of a BEC is well understood analytically [3]. Interferometric fringe contrast of an expanding BEC is strongly influenced by the thermal component of the gas and anharmonicity of the release trap. We aim to realistically simulate the expansion of a BEC from the atom chip trap of QUANTUS-2 [1] by including elementary excitations and also anharmonicities of the release trap. This is done as part of a comprehensive simulation suite for a realistic atom interferometer being developed for comparison with experimental data.

[1] QUANTUS Collaboration:www.iqo.uni-hannover.de/quantus

[2] T. van Zoest et al., Science, **328**, 1540 (2010) and H. Mütinga et al., Phys. Rev. Lett., **110**, 093602 (2013).

[3] Yu Kagan et al., Phys. Rev. A, **54**(3), R1753 (1996) and Y Castin et al., Phys. Rev. Lett., **77**(27), 5315 (1996).

Q 53.31 Thu 17:00 P OGs

Cold quantum gases in adaptive scales — •Jan Teske and Reinhold Walser — Institut für Angwandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt, D-64289, Germany

The research field of the QUANTUS collaboration are ultracold quantum gases in weightlessness. These experiments are performed at the drop tower in Bremen (ZARM). During the free fall of several seconds the released Bose-Einstein condensate reaches macroscopic system sizes being used for precise measurements of accelerations and rotations [1, 2].

For the analysis of the complex matter wave-optics setup, we have developed a software package, *MatterWaveSim*, including classical ray tracing, beam splitter and magnetic chip trap simulations. In the present contribution we present appropriate numerical methods for Bose-Einstein condensates. We introduce introduce adaptive scales [3] for modelling finite temperature dynamics of an ultracold Bose gas. In particular we study the long time expansion and delta kick cooling with realistic magnetic chip traps.

[1] G. Nandi, R. Walser, E. Kajari, and W. P. Schleich. Dropping cold quantum gases on earth over long times and large distances. *Phys. Rev. A*, **76**, 063617 (2007).

[2] H. Müntinga *et al.* Interferometry with Bose-Einstein Condensates in Microgravity. *Phys. Rev. Lett.* **110**, 093602 (2013).

[3] Y. Castin, R. Dum. Bose-Einstein Condensates in Time Dependent Traps. *Phys. Rev. Lett.* **77** (1996).

Q 53.32 Thu 17:00 P OGs

Superconducting coherent electron beam sources and a compact matter wave interferometer for sensor applications — •Nicole Kerker, Andreas Pooch, Georg Schütz, Michael Seidling, Moritz Layer, Nicolas Seitz, and Alexander Stibor — University of Tübingen, Physical Institute, Quantum Electron - & Ion - Interferometry

In interferometry significant developments of novel techniques where made. They include coherent single atom tip field emitters or delay line detectors with high spatial and temporal resolution which allows correlation analysis. These techniques can be applied in electron interferometry to construct sensors with high sensitivity for rotations or the spectroscopy of vibrational and electromagnetic frequencies. The realization of such a sensor requires a highly coherent and intensive electron field emission source and a compact, robust and portable electron interferometer. Here, we present new developments towards these goals. Increasing electron beam coherence by simultaneously remaining a high intensity can in principle be achieved using niobium tips. Niobium gets superconducting below a temperature of 9.2 K and it has been demonstrated in the literature that the energy spread of the emitted electrons in this regime decreases significantly. We show first results in the preparation of such tips and the characterization of their field emission behavior. We present the design and realization of a compact and robust electron biprism interferometer. The setup can potentially be applied to realize a portable interferometer to test the coherent properties of novel beam emitters and for sensor applications.

Q 53.33 Thu 17:00 P OGs

Second-order correlation analysis for single particle interferometry with applications in sensor technologies — •Robin Röpke[1], Alexander Rembold[1], Georg Schütz[1], Andreas Günther[2], and Alexander Stibor[1] — [1]University of Tübingen, Physical Institute, Quantum Electron - & Ion - Interferometry — [2]University of Tübingen, Physical Institute, Nano Atomoptics

The high phase sensitivity of single particle interferometers makes them susceptible to dephasing perturbations such as mechanical vibrations and electromagnetic oscillations. They can decrease the spatial information and wash-out the interference pattern, leading to a loss of contrast. This is a problem for precision phase measurements especially the perturbing environment can never be perfectly shielded. We demonstrate a method to identify and correct multiple perturbation frequencies with different amplitudes by using spatial and temporal correlations. With a delay line detector we get the spatial and temporal information in a high resolution. This allows a correlation data analysis that significantly reduces the effects of dephasing and allows the reconstruction of the original spatial fringe pattern. We provide a full theoretical description based on second-order correlation theory combined with Fourier analysis. The theory is applied on measurement data from an electron interferometer that has been vibrationally disturbed and electromagnetically dephased by multiple simultaneous oscillations. We demonstrate that our method can extract unknown perturbation frequencies from a washed-out interference pattern which can be applied in sensor technology to analyze external frequencies.

Q 53.34 Thu 17:00 P OGs

Trade-off of atomic sources for extended-time atom interferometry — •Sina Loriani, Dennis Schlippert, Christian Schubert, Ernst Maria Rasel, and Naceur Gaaloul — Leibniz University of Hanover, Germany

Proposals for atom-interferometry based sensors designed to detect gravitational waves or testing the universality of free fall assume unprecedented sensitivity for long interferometry times [Hogan et al., Phys. Rev. A 94, 033632, (2016)]. These long drift times of several seconds can be achieved by operation in microgravity and by using phase-space-manipulation techniqes like the delta-kick-collimation(DKC), which drastically reduces the expansion rate of atomic samples [Müntinga, et al. Phys. Rev. Lett. **110**, 093602 (2013), T. Kovachy et al., Phys. Rev. Lett. **114**, 143004 (2015)]. We present a set of theoretical models that treat the impact of collisions and mean-field on the performance of the kick and compare the efficiency of the collimation for all possible temperature and density regimes. The theoretical study covers commonly used alkaline and alkaline-earth-like ensembles of atoms (Rb, Sr, Yb, etc.). The figure of merit is the size of the ensemble when being lensed as the atomic lenses are subject to aberrations depending on the spatial extent of the cloud and the potentials being used. The analysis shows a clear advantage when using condensed ensembles.

Q 53.35 Thu 17:00 P OGs

Theoretical study of Bose-Einstein condensates in optical 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

Highly sensitive atom interferometers require the two interferometer arms to enclose a large area in spacetime.

In parallel to the implementation of large interrogation times in microgravity [1] and fountains [2], a larger spatial separation with large momentum transfer (LMT) enhances the sensitivity of atomic sensors. A promising method to realize these novel schemes is to combine Bragg pulses and Bloch oscillations in optical lattices to coherently split and recombine the atomic wave packets. However, the finite momentum width of the atomic ensemble or the damping of Bloch oscillations due to tunneling constrain the fidelity of the LMT.

We theoretically analyze the coherent acceleration of BECs in 1D optical lattices to understand and optimize pioneering experiments performed in the QUANTUS collaboration. To this end, a 1D-reduced Gross-Pitaevskii model[3] is adapted to interpret and propose realistic novel LMT schemes.

[1] H. Muentinga et al. Phys. Rev. Lett. 110, 093602 (2013)
[2] S. M. Dickerson et al. Phys. Rev. Lett. 111, 083001 (2013)
[3] L. Salasnich et al. Phys. Rev. A 66, 043613 (2002)

Q 53.36 Thu 17:00 P OGs

Fast BEC transport with atoms chips for inertial sensing — •Robin Corgier[1], Sirine Amri[2], Eric Charron[2], Ernst Maria Rasel[1], and Naceur Gaaloul[1] — [1]Leibniz University of Hanover, Germany — [2]Université Paris-Sud, France

Recent proposals in the field of fundamental tests of foundations of physics assume Bose-Einstein condensates (BEC) as sources of atom interferometry sensors. Atom chip devices have allowed to build transportable BEC machines with high repetition rates as demonstrated in the QUANTUS project. The proximity of the atoms to the chip surface is, however, limiting the optical access and the available interferometry time necessary for precision measurements. In this context, a fast and perturbation-free transport of the atoms is required. Shortcuts to adiabaticity protocols were proposed and allow in principle to implement such sequences with well defined boundary conditions. In this theoretical study, one can engineer suitable protocols to move atomic ensembles trapped at the vicinity of an atom chip by tuning the values of the realistic chip currents and external magnetic fields. Experimentally applicable trajectories of the atomic trap optimizing the transport time and reducing detrimental effects due to the offset of atoms positions from the trap center are found using a reverse engineering method. We generalize the method in order to optimize the size evolution and the center of a BEC wave packet in phase space. This allows an efficient delta-kick collimation to the pK level as observed in the Quantus 2 experiment. With such low expansion rates, atom interferometry experiments with seconds of drift time are possible.

Q 53.37 Thu 17:00 P OGs

Optical systems for BEC-based atom interferometry on the sounding rocket mission MAIUS-I — •André Wenzlawski[1], Kai Lampmann[1], Moritz Mihm[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and the MAIUS team[1,2,3,4,5,6] — [1]Institut für Physik, JGU Mainz — [2]Institut für Laserpyhsik, U Hamburg — [3]Institut für Quantenoptik, LU Hannover — [4]ZARM, Bremen — [5]Institut für Physik, HU Berlin — [6]FBH, Berlin

Atom interferometry in space is gaining ever-increasing interest because of the accessible interrogation times exceeding what is possible on ground by orders of magnitude and thus allowing unprecedented sensitivities. This may enable more precise tests in fundamental physics like a test of the equivalence principle or detection of gravitational waves. As a first step towards realizing atom interferometry based precision measurements in space, the sounding rocket MAIUS-I was launched this winter from northern swedish Esrange demonstrating the technological and scientific feasibility of these kind of experiments.

Here we will present the optical system for the MAIUS-I experiment, used to cool and manipulate an ensemble of ^{87}Rb atoms as well as the scheme for autonomous frequency stabilization of the lasers with respect to a hyperfine transition of ^{85}Rb.

The MAIUS 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 50WM1131-1137.

Q 53.38 Thu 17:00 P OGs

Matterwave Sagnac interferometer using state dependent guiding of atoms in a ring trap. — •Fabio Gentile, Thomas Bishop, Jamie Johnson, Mark Bason, Sindhu Jammy, Tadas Pyragius, Hans Marin Florez, and Thomas Fernholz — The University of Nottingham - NG7 2RD - UK

We present an experimental procedure for the implementation af a matterwave rotation sensor. Recently many progresses have been achieved in atom-based Sagnac interferometry, such as improved sensitivity and elimination of dead times [1]. Differently from other experiments, in our scheme atoms are confined during all the interferometric sequence [2]. Instead of making use of free wave propagation, atomic clouds are steered around a ring trap in a controlled fashion [3,4]. This particular feature opens possibilities for miniaturization of the experimental apparatus towards the realization of compact devices.

[1] PhysRevLett.116.183003(5) (2016) [2] Proc. SPIE 9900, Quantum Optics, 990007 [3] PhysRevLett.115.163001(6) (2015) [4] PhysRevA.75.063406(6) (2007)

Q 53.39 Thu 17:00 P OGs

Atom Interferometry in Space — •Maike D. Lachmann[1], Dennis Becker[1], Stephan T. Seidel[1], Ernst M. Rasel[1], Wolfgang Ertmer[1], and Collaboration QUANTUS[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]LUH, JGU, UHH, FBH, HUB, ZARM, UULM, TUDA, DLR

Atom interferometry with Bose-Einstein condensates (BEC) in space is a promising approach towards a precise test of the equivalence principle. As a first step atom interferometers utilizing sounding rockets are currently being built within the QUANTUS collaboration. With the first rocket mission MAIUS-1 we plan to create BECs and to demonstrate light-pulse atom interferometry in space for the first time.

The presented apparatus uses Rubidium-87 atoms and can create BECs of 10^5 atoms within two seconds. Thanks to this high repetition rate we can perform more than 70 experiments during the six minutes of microgravity. They will adress different aspects of atom interferometry ranging from state preparation, observation of the phase transition to Stern-Gerlach type experiments and analysis of the coherence of a BEC after long free evolution times using magnetic lensing and atom interferometers.

Due to the high constraints of the rocket the payload is optimized in respect to volume, mass and low power consumption. The apparatus was qualified for the flight using vibrational tests and the launch is scheduled for the end of 2016.

On the poster the setup and the results of the MAIUS-1 flight will be presented.

Q 53.40 Thu 17:00 P OGs

Ultra-stable laser for a magnesium lattice clock — •Steffen Sauer, Steffen Rühmann, Dominka Fim, Klaus Zipfel, Nandan Jha, Waldemar Friesen, Pia Koopmann, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

One of the key elements for an optical frequency standard are ultra-stable lasers for probing narrow optical transitions. At IQ in Hanover, we are working towards development of an optical lattice clock based on bosonic magnesium [1]. In such clocks the atoms are trapped in optical lattices enabling Doppler- and recoil-free spectroscopy. This sets stringent requirements on the short term stability of the clock lasers performing the spectroscopy.

We report on the progress and performance of our ultra-stable laser system and its distribution to the interrogation chamber. The laser system interrogating the clock transition consists of a diode laser system at 916 nm stabilized to a high finesse cavity isolated from environmental perturbations. The light is transmitted via a 30 m long fiber to a second-harmonic generator (SHG) and frequency doubled to the clock transition wavelength at 458 nm. To suppress the frequency fluctuations induced by this 30 m long fiber, we have implemented an active fiber length stabilization system. Afterwards frequency doubled light is fed via another stabilized fiber to the atoms. Following various improvements we achieve an instability of 4×10^{-16} in 1 s for the laser itself, which is close to the calculated thermal noise floor level.

[1] Kulosa et al., Phys. Rev. Lett. **115**, 240801 (2015)

Q 53.41 Thu 17:00 P OGs

Collective effects in driving the ^{229}Th nuclear transition — •Brenden S. Nickerson and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The high accuracy of atomic clocks lies behind the success of the Global Positioning System, which requires synchronization of orbiting satellites for triangulation. More precise clocks are desirable for challenging Einstein's theory of general relativity or for Earth-observation satellites tracking the sea level, and would generally allow to push the bounds of observable physics. 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]. This level is a nuclear isomeric state at approx. 7.8 eV that can be reached by VUV lasers. 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 the possibility to exploit collective effects in order to design a more sensitive nuclear excitation scheme in the process of scattering of light through a Th-doped crystal. The crystalline environment enforces the Mössbauer regime, allowing for recoil-free emission and absorption and collective behaviour [3]. By taking advantage of such effects we aim 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 53.42 Thu 17:00 P OGs

Realization of magnesium optical lattice clock — •Nandan Jha, Dominika Fim, Klaus Zipfel, Steffen Rühmann, Steffen Sauer, Waldemar Friesen, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten-1, 30167 Hannover, Germany

Optical lattice clocks have already reached performance levels better than the best Cs fountain clocks. Magnesium with a high-Q $^1S_0 \rightarrow {}^3P_0$ optical transition and a small black body radiation shift is a promising candidate for an optical frequency standard. We present the progress towards the realization of such an optical lattice clock on the dipole forbidden $^1S_0 \rightarrow {}^3P_0$ transition of bosonic ^{24}Mg. The precision of our previous spectroscopy measurements of the $^1S_0 \rightarrow {}^3P_0$ clock transition [1] was limited by the line broadening (order of 10's of kHz) due to tunneling in the relatively shallow optical lattice, and spatial inhomogeneity of the magnetic field used to induce mixing between $^3P_0$ and $^3P_1$ states. We overcome these limitations by going to deeper lattice potential and hence reducing the atomic tunneling between the lattice sites. Further improvements in magnetic field stability and clock laser frequency distribution have allowed us to reduce the linewidth of the clock transition to around 100 Hz. This higher Q-factor enables a more precise measurement of the magic wavelength and the other systematic shifts.

[1] A. Kulosa et al., Phys. Rev. Lett. **115**, 240801 (2015).

Q 53.43 Thu 17:00 P OGs

Towards cavity enhanced magnetometry based on the infrared transition of NV centers in diamond — Himadri Chatterjee[1], •Andrew Edmonds[2], Alexander Bommer[1], Benjamin Kambs[1], and Christoph Becher[1] — [1]Universität des Saarlandes, Fakultät NT, Fachrichtung-Physik, Campus E2.6, 66123 Saarbrücken — [2]Element Six Ltd., Global Innovation Centre, Fermi Avenue, Harwell Oxford, Didcot OX11 0QR, UK

In recent years the nitrogen vacancy (NV) centers in diamond became a prime candidate for sensing applications. It can work e.g. as a sensor of electric and magnetic fields, pressure and temperature. The commonly used technique for sensing purposes is Optically Detected Magnetic Resonance (ODMR), which uses the red fluorescent light from the NV centers. The challenge in such a method is the low collection efficiency of fluorescence due to high refractive index of diamond, which traps most of the red fluorescence light inside the diamond sample by total internal reflection. Improving sensitivity thus requires improvement of the detection of spin selective fluorescence from the NV centers. To circumvent this problem and to achieve higher sensitivity alternative approach is to use the optical absorption of the infrared transition (1042 nm) in the singlet spin sates of the NV centers. At room temperature the homogeneous broadening of the infrared resonance reduces the absorption of an infrared probe laser. In this work we present work towards using a monolithic cavity to enhance the IR absorption in order to achieve highly sensitive magnetometer operation at room temperature.

Q 53.44 Thu 17:00 P OGs

Automatization of a spaceborne iodine frequency reference based on a diode laser at 1064 nm — •Franz Gutsch[1], Klaus Döringshoff[1], Vladimir Schkolnik[1,2], Markus Krutzik[1], Achim Peters[1,2], and The JOKARUS Team[1,2,3,4,5,6] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]FBH, Berlin — [3]ZARM U Bremen — [4]DLR Bremen — [5]JGU Mainz — [6]Menlo Systems GmbH

Spaceborne laser-based frequency references can deliver high accuracy and stability needed to further explore the foundational principles of General Relativity in future experiments, such as tests of the gravitational redshift or gravitational wave astronomy (e.g. eLISA).

We present a compact frequency reference based on Doppler-free MTS of molecular iodine at 532 nm, which is optimized for autonomous operation onboard a TEXUS sounding rocket starting fall 2017. Utilizing an externally frequency-doubled ECDL MOPA system, the JOKARUS mission poses new challenges on the automatization and reliable operation in harsh environments as well as providing a proof of concept for spaceborne operation. In this poster, we focus on system control and autonomy concepts as well as their possible merit for controlling similar optical clock setups.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM 1646.

Q 53.45 Thu 17:00 P OGs

Near-field microwave control of trapped ions for scalable quantum simulation and quantum information processing — •G. Zarantonello[1,2], H. Hahn[1,2], S. Grondkowski[1], T. Dubielzig[1], F. Ude[1], M. Wahnschaffe[2,1], A. Bautista-Salvador[2,1], and C. Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig

Recent experiments have shown promising approaches to quantum simulation and information processing with trapped ions using microwave fields rather than the commonly used focused laser beams. In one approach [1], the ion's internal states are coupled to motional states by means of microwave near-field gradients [2]. Here, we integrate a single conductor in a surface-electrode trap to generate the required near-field gradient [3]. We present finite element simulations of the magnetic field and show agreement with experimental results at the sub-micron and few-degree level within an intuitive field model [4]. We show the current experimental setup, present an enhanced, multi-layer ion trap and corresponding field simulations with improved near-field characteristics. We also discuss a new vacuum system with built-in Ar^+ bombardment for surface electrode cleaning to suppress motional heating.

[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.*, arXiv:1601.06460v2 [quant-ph] (2016).

Q 53.46 Thu 17:00 P OGs

Anticoherence measures for spin states — •Dorian Baguette and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, Université de Liège, Bât. B15, B - 4000 Liège, Belgium

Among all possible spin states, spin-coherent states are the most classical because the spin expectation value in these states yields a vector of maximal norm pointing in a well defined direction $\mathbf{n}$. In contrast, anticoherent spin states to order t are such that $\langle(\mathbf{J}\cdot\mathbf{n})^k\rangle$ is independent of the unit vector $\mathbf{n}$ for $k = 1, \ldots, t$ [1]. By construction, coherent and anticoherent spin states are at both ends of the spectrum of classicality. The aim of this work is to position all possible spin states on such a spectrum, that is to provide measures of anticoherence. To this aim, we introduce an axiomatic definition of anticoherence measures to any order t. In particular, we show that the total variance of a pure spin state, first introduced in [2], can be used to define a measure of anticoherence to order 1. We describe a systematic way of constructing anticoherence measures to any order that relies on the mapping between spin-j states and symmetric states of $2j$ spin-1/2. In particular, we exploit the fact that anticoherent spin states to order t have maximally mixed t-spin-1/2 reduced density matrices in the symmetric subspace [3].

[1] J. Zimba, Electron. J. Theor. Phys. **3**, 143 (2006). [2] A. A. Klyachko, B. Öztop, and A. S. Shumovsky, Phys. Rev. A **75**, 032315 (2007). [3] D. Baguette, T. Bastin, and J. Martin, Phys. Rev. A **90**, 032314 (2014).

Q 53.47 Thu 17:00 P OGs

Exact zeros of entanglement for arbitrary rank-two mixtures derived from a geometric view of the zero polytope — •Andreas Osterloh — Universität Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg

Here I present a method how intersections of a certain density matrix of rank two with the zero-polytope can be calculated exactly. This is a purely geometrical procedure which thereby is applicable to obtaining the zeros of SL- and SU-invariant entanglement measures of arbitrary polynomial degree. I explain this method in detail for a recently unsolved problem. In particular, I show how a three-dimensional view, namely in terms of the Boch-sphere analogy, solves this problem immediately. To this end, I determine the zero-polytope of the three-tangle, which is an exact result up to computer accuracy, and calculate upper bounds to its convex roof which are below the linearized upper bound. The zeros of the three-tangle (in this case) induced by the zero-polytope (zero-simplex) are exact values. I apply this procedure to a superposition of the four qubit GHZ- and W-state. It can however be applied to every case one has under consideration, including an arbitrary polynomial convex-roof measure of entanglement and for arbitrary local dimension.

Q 53.48 Thu 17:00 P OGs

Continuous-variable quantum teleportation can enhance probabilistic discrete-variable quantum gates — •Fabian Ewert and Peter van Loock — Johannes Gutenberg-Universität Mainz

We propose a linear optical generalization of the probabilistic nonlinear sign-shift gate, presented by KLM [Nature 409, 46-52 (2001)] that approximates a strong self-kerr interaction up to the d-photon Fock state. Applying this highly probabilistic gate to the resource state of a continuous-variable quantum teleportation and replacing the standard correcting operation, i.e. a displacement, by a nonlinear displacement yields a nonlinear sign-shift gate on the input mode of the teleportation setup. By choosing d large enough and conditioning the teleportation accordingly, the success probability of this gate can be pushed above the 25% limit of the KLM gate while maintaining a near-unit fidelity. This can also be used to implement a controlled-SIGN gate with a probability higher than the current linear-optics maximum of 2/27.

Q 53.49 Thu 17:00 P OGs

Long-range Rydberg-blockade entangling gate mediated by auxiliary atoms — •Alexandre Cesa and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, Université de Liège, Bât. B15, B - 4000 Liège, Belgium.

Arrays of qubits encoded in the ground state manifold of trapped neutral atoms appear as a promising platform for the realisation of a scalable quantum computer. Indeed, such physical qubits have a long coherence time and allow for high-fidelity single-qubit operations [1]. In such a platform, entangling two-qubit gates can be implemented by exploiting the Rydberg-blockade mechanism to produce a phase shift or a flip of the state of a target atom conditioned on the state of a control atom [2]. However, because dipole-dipole interactions fall off rapidly with the interatomic distance, such entangling gates based on Rydberg-blockade are impractical between distant qubits. In this work, we propose a protocol to implement long-range Rydberg-blockade gates (CZ or CNot) using auxillary non-coding atoms to transfer the Rydberg excitation from the control to the target qubit. The dependence of the fidelity on the number of auxillary atoms, the blockade strength and the decay rates of the Rydberg states are determined. When compared to a sequential application of nearest neighbours entangling gates, our protocol leads to a larger fidelity and a reduction of the overall gate duration (which scales linearly with the number of auxillary atoms).

[1] M. Saffman, J. Phys. B: At. Mol. Opt. Phys. 49, 202001 (2016).
[2] D. Jaksch, J. I. Cirac, P. Zoller, S. L. Rolston, R. Côté, and M. D. Lukin, Phys. Rev. Lett. 85, 2208 (2000).

Q 53.50 Thu 17:00 P OGs

Entangling atoms over a large distance — •Robert Garthoff[1], Daniel Burchardt[1], Kai Redeker[1], Norbert Ortegel[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Entanglement between widely separated quantum systems is a key resource in various quantum communication protocols. These include the recently performed conclusive tests of Bell's inequality [1], quantum repeaters and device-independent quantum key distribution.

We present the experimental details on our system of two single Rb-87 atoms trapped in laboratories separated by a distance of 400 meters. Starting with atom-photon entanglement we employ the entanglement swapping protocol to generate heralded entanglement between the atoms. We discuss the issues of coherence time, long-term stability, quality of two-photon interference, and atomic state fidelity which are critical for using this system as a testing platform for a quantum repeater or device-independent protocols.

[1] arXiv:1611.04604 [quant-ph]

Q 53.51 Thu 17:00 P OGs

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

The impossibility of perfectly discriminating non-orthogonal states is vital for quantum key-distribution. In classical communication, however, it imposes strict constraints on the channel capacity. Along with the technological progress, the average optical power per symbol has been continuously decreasing and conventional receiver designs are approaching their sensitivity limit - the standard quantum limit (SQL). Quantum mechanics allows for a much lower error probability compared to SQL, the Helstrom bound. Optimal and near-optimal strategies have been experimentally demonstrated for binary phase-shift keying (PSK) [1]. For quadrature PSK, a hybrid receiver, based on a combination of homodyne- and single photon detection, was demonstrated to outperform the SQL for any signal power [2]. Moreover, a feedback supplemented strategy with photon number resolution technology was proposed [3], and research is in progress to realize it experimentally using FPGAs for real-time feedback. We review the recent progress on quantum receivers and compare different strategies on performance and robustness against technical imperfections.

[1] C. Wittmann et al., Phys. Rev. Lett. 101, 210501 (2008)
[2] C. R. Müller et al., New J. Phys. 14, 083009 (2012)
[3] C. R. Müller et al., New J. Phys. 17, 032003 (2015)

Q 53.52 Thu 17:00 P OGs

Integration of a high-speed continuous-variable quantum random number generator — Imran Khan[1,2], Christoph Pacher[3], •Jonas Pudelko[1,2], Momtchil Peev[4], Bernhard Schrenk[3], Winfried Boxleitner[3], Edwin Querasser[3], Christoph Varga[3], Philipp Grabenweger[3], Christoph Marquardt[1,2], and Gerd Leuchs[1,2,5] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [2]Institut of Optics, Information and Photonics, Friedrich-Alexander University Erlangen-Nuremberg (FAU), Staudtstr. 7/B2, 91058 Erlangen, Germany — [3]AIT Austrian Institute of Technology, Donau-City-Strasse 1, 1220 Vienna, Austria — [4]Huawei Technologies Duesseldorf GmbH, German Research Center, Riesstrasse 25, 80992 München — [5]Department of Physics, University of Ottawa, 25 Templeton, Ottawa, ON, Canada

Random numbers play an essential role in many applications, such as quantum key distribution, simulations and classical cryptography. In this work, we discuss the photonic and electronic integration of a quantum random number generator (QRNG) based on measurements on the quantum mechanical vacuum state. The experimental setup is based on an InP photonic integrated circuit, containing all required components on a 4 x 4.6 mm chip. This could give access to a portable and reliable QRNG potentially achieving rates in the GHz regime.

Q 53.53 Thu 17:00 P OGs

Generating entanglement between a trapped ion and the time-bin of a photon — •Konstantin Friebe[1], Moonjoo Lee[1], Dario A. Fioretto[1], Markus Teller[1], Klemens Schüppert[1], Florian R. Ong[1], Pierre Jobez[1], Florian Kranzl[1], Rainer Blatt[1,2], and Tracy E. Northup[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Innsbruck, Österreich — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck, Innsbruck, Österreich

While small-scale quantum computers, e.g., based on trapped ions, are already in existence, scaling up to larger numbers of qubits proves technically challenging. One possible solution to this problem is a distributed quantum computer, consisting of several small-scale quantum computers, linked together in a quantum network. Such linking of separate quantum nodes is also a requirement for building quantum repeaters for long-distance quantum communication.

Here, we describe the current status of our quantum node at the Universität Innsbruck: we report on the implementation of a laser beam for addressing single ions in a crystal of multiple trapped ions, and describe a protocol and its implementation for the generation of entanglement between the electronic state of one trapped ion and the time-bin degree of freedom of a single photon. This protocol is an alternative to the more standard encoding of quantum information in the polarization degree of freedom of photons and can thus be used for systems in which well-defined photon polarization can not be achieved.

Q 53.54 Thu 17:00 P OGs

Silicon-Vacancy Color Centers in Diamond at Millikelvin Temperatures — •Alexander Stahl[1], Max Hettrich[1], Mathias Metsch[2], Michael Kern[2], Lachlan J. Rogers[2], Fedor Jelezko[2], and Ferdinand Schmidt-Kaler[1] — [1]WA Quantum, Johannes Gutenberg - Universität Mainz — [2]Institut für Quantenoptik, Universität Ulm

Color centers in diamond represent excellent qubits without the need for ultrahigh vacuum and complex lasersystems[1,2]. In particular, silicon-vacancy color centers feature very narrow optical transitions due to the conservation of the diamond crystal's inversion symmetry. This makes them excellent sources for indistinguishable photons, which can be used for entanglement distribution. However, the phonon-induced dynamic Jahn-Teller effect severely limits the ground-state spin coherence time to about 35 ns[3,4]. We are setting up an apparatus featuring a dilution refrigerator, which is able to cool a diamond sample together with a single-site resolving confocal microscope to Millikelvin temperatures, which is expected to increase that coherence time by several orders of magnitude. Possibilities for future extensions include photonic structures of the diamond around the color center for enhanced coupling and CQED applications.

[1] D. D. Awschalom et al., Science 339, 1174 (2013
[2] F. Jelezko et al., Phys. Rev. Lett. 92, 076401 (2004)
[3] L. J. Rogers et al., Phys. Rev. Lett. 113, 263602 (2014)
[4] B. Pingault et al., Phys. Rev. Lett. 113, 263601 (2014)

Q 53.55 Thu 17:00 P OGs

Generation and evaluation of entangled multipartite nuclear spin states — •Stefan Jesenski, Sebastian Zaiser, Johannes Greiner, Philipp Neumann, Durga Dasari, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Multipartite entangled states are key for many quantum information protocols. Generation of these states and their protection against various noise sources is quintessential for successful quantum computing and sensing applications. Here we discuss the generation and minimally invasive characterization of multipartite entangled nuclear spin states coupled to a single Nitrogen-Vacancy center (NV) in diamond. At low temperatures, resonant optical excitation of the NV becomes possible allowing for high fidelity projective spin readout and spin initialization. In combination with spin-lifetimes many orders of magnitude higher compared to ambient conditions, generation of multipartite entangled states becomes plausible by optical methods possibly assisted by microwave fields. We present a scheme and evaluate the fidelities involved in optimal generation and measurement of five qubit entangled states for realistic parameters.

Q 53.56 Thu 17:00 P OGs

Towards the realisation of an atom trap in the evanescent field of a microresonator — •Luke Masters, Elisa Will, Michael Scheucher, Adèle Hilico, Jürgen Volz, and Arno Rauschenbeutel — VCQ, Atominstitut, TU Wien, 1020 Vienna, 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 $85Rb$ atoms in the vicinity of a bottle-microresonator - a highly prolate type of WGM resonator. A standing wave optical dipole trap is created by retroreflecting a tightly focussed beam on the BMR surface (method similar to [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 characterizations of our trap.

[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. arXiv:1609.02492v1,
[4] J. D. Thompson et al. Science 340, 1202 (2013).

Q 53.57 Thu 17:00 P OGs

Fabrication of micro resonator mirrors using CO_2 laser — •Max Deisböck, Stefan Häussler, Andrea Kurz, Riccardo Cipolletti, and Alexander Kubanek — Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany

Cavity QED is a highly innovative and fast growing field. It investigates the interaction between optical transitions of single atoms and light within an optical resonator. In former times this would just have been a textbook example. In the meantime there was tremendous technological progress e.g. in stabilizing cavities, producing mirrors with the required quality and control of atomic systems, so that the example becomes reality. In order to reach cavity QED regime the coupling rate g needs to be optimized. Therefore either the mode volume V has to be kept small or the quality factor Q has to be large.

Production of resonator mirrors faces many challenges in order to achieve high quality. This includes the control of inhomogeneities, impurities and surface roughness.

Here, we want to achieve small V for high finesse cavities. Therefore, we need good surface quality and high radius of curvature (ROC). We want to realize the goal using a CO_2 laser that is tightly focused. We aim to create structures with ROC fundamentally limited by CO_2 laser wavelength.

Q 53.58 Thu 17:00 P OGs

Strong coupling between nanofiber-trapped atoms and fully fiber-integrated Fabry-Perot microresonator — •Martin Blaha, Sarah M. Skoff, and Arno Rauschenbeutel — Vienna University of Technology, Stadionallee 2, A-1020 Vienna, Austria

For building key components of optical quantum networks, such as quantum memories, an efficient interaction between light and suitable quantum emitters is required. Moreover, the latter is a prerequisite for establishing interactions between individual photons by means of an optical nonlinearity.

In order to realize such an efficient light-matter interface, we plan to couple cold Cesium atoms to a fully fiber-integrated high-Q microresonator. The backbone of this experiment is a tapered optical fiber containing a sub-wavelength diameter waist. Using a two-color optical dipole trap, we interface an ensemble of laser-cooled atoms via the nanofiber waist, which is enclosed by two fiber Bragg gratings. They form a high-Q resonator for the D2 line of Cesium, while transmitting the trapping light.

This scheme combines cavity enhancement and collective coupling in a single system and thus allows one to reach a very large collective light-matter coupling strength, required to implement, e.g. an inherently fiber-coupled quantum memory. Further, we aim to use the strong coupling between the atoms and the light to observe cross-phase modulation of a probe pulse by the intensity of a signal pulse. This photon-photon interaction would then be a key ingredient for optical quantum information processing.

Q 53.59 Thu 17:00 P OGs

Quantum simulators for open quantum systems using quantum Zeno dynamics — •Sabrina Patsch and Christiane P. Koch — Universität Kassel, Deutschland

A watched quantum arrow does not move. This effect, referred to as the quantum Zeno effect, arises from a frequent measurement of a quantum system's state. In more general terms, the evolution of the quantum system can be confined to a subspace of the system's Hilbert space leading to quantum Zeno dynamics. Resulting from the measurement process, a source of dissipation is introduced into the systems dynamics. However, different than for a common open quantum system, we can choose the strength of the dissipation by changing the parameters of the Zeno measurement.

We capitalise on the property of tunable dissipation to create a quantum simulator for open quantum systems. Due to the formal analogy of the measurement process and the theory of open quantum systems, we can derive a Lindblad master equation to describe the evolution of the open quantum system. Moreover, we extend the picture to enable also non-Markovian evolution in the quantum simulator.

The considered quantum system are photons inside a cavity being subject to a indirect measurement using circular Rydberg atoms. The setup is inspired by Zeno experiments proposed in the framework of cavity quantum electrodynamics [1].

[1] Raimond et al. Quantum Zeno dynamics of a field in a cavity.*Phys. Rev. A* 86, 032120 (2012)

Q 53.60 Thu 17:00 P OGs

Macrorealistic extensions of relativistic quantum theory — •Silas Bischoff and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

Modifications of non-relativistic quantum mechanics, such as the well known GRW and CSL models [1], are already well understood. In contrast to purely interpretative approaches to quantum foundational problems, macrorealistic extensions yield quantitative predictions that allow for experimental falsification. However, the reconciliation of macrorealism with special relativity is laden with conceptual difficulties hitherto unresolved. We aim to understand and formalize the properties a macrorealistic modification of relativistic QFT is required to exhibit. To that end we critically analyse specific proposals [3-4].

[1] Bassi et al., Rev. Mod. Phys. 85, 471-527 (2013)
[3] Bedingham, Found. Phys. 41, 686 (2011)
[4] Pearle, Phys. Rev. D 91, 105012 (2015)

Q 53.61 Thu 17:00 P OGs

Master equations for disordered quantum systems — •Chahan Kropf and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, D-79104, Freiburg, Deutschland

Recent experimental implementations of finite-size disordered systems with cold atoms or photonic circuits allow to study the dynamics of the state obtained by averaging over all realizations of the disorder, on transient time scales, and/or far from the thermodynamic limit. In [1], we showed that, in these regimes, the effective decoherence arising from the ensemble averaging procedure can be efficiently characterized in terms of generalized master equations.

Here we show that, using perturbation theory, which is needed to diagonalize the Hamiltonians of the single realizations of the disorder prior to the ensemble average, we can now describe a wide range of systems such as disordered lattice (Anderson-like) models, disordered transport networks or disordered Bose-Hubbard models.

[1] C. Kropf, C. Gneiting, and A. Buchleitner, Phys. Rev. X **6**, 031032 (2016)

Q 53.62 Thu 17:00 P OGs

Operational description of a momentum observable — •Fabio Di Pumpo, Hannes Weber, and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, 89069 Ulm

We present the definition of an operational momentum operator. This definition is motivated by a classical time-of-flight measurement which we model by a Hamiltonian for a particle interacting with two quantum pointers at different times. We solve the corresponding dynamics in the Heisenberg picture. Our aim then is to calculate the optimized bipartite pointer state, so that the statistics of the operational momentum operator resembles the one of the original momentum operator describing the single-particle system.

Q 53.63 Thu 17:00 P OGs

Laser and cavity cooling of a mechanical resonator with a nitrogen-vacancy center in diamond — •Luigi Giannelli[1], Ralf Betzholz[1], Laura Kreiner[2], Marc Bienert[1], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Experimentalphysik, Universität des Saarlandes, 66123 Saarbrücken, Germany

We theoretically analyze the cooling dynamics of a high-Q mode of a mechanical resonator, when the structure is also an optical cavity and is coupled with a nitrogen-vacancy (NV) center. The NV center is driven by a laser and interacts with the cavity photon field and with the strain field of the mechanical oscillator, while radiation pressure couples the mechanical resonator and cavity field. Starting from the full master equation we derive the rate equation for the mechanical resonator's motion, whose coefficients depend on the system parameters and on the noise sources. We then determine the cooling regime, the cooling rate, the asymptotic temperatures, and the spectrum of resonance fluorescence for experimentally relevant parameter regimes. For these parameters, we consider an electronic transition, whose linewidth allows one to perform sideband cooling, and show that the addition of an optical cavity in general does not improve the cooling efficiency. We further show that pure dephasing of the NV center's electronic transitions can lead to an improvement of the cooling efficiency.

Q 53.64 Thu 17:00 P OGs

Recent progress in generating squeezed vacuum states in a nonlinear crystalline whispering gallery mode resonator — •Alexander Otterpohl[1,2], Gerhard Schunk[1,2], Ulrich Vogl[1,2], Florian Sedlmeir[1,2], Golnoush Shafiee[1,2], Dmitry Strekalov[1,2], Tobias Gehring[3], Harald G. L. Schwefel[4], Ulrik L. Andersen[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 of Erlangen-Nuremberg, Staudtstr. 7 B2, 91058 Erlangen, Germany — [3]Department of Physics, Technical University of Denmark, Fysikvej, 2800 Kgs. Lyngby, Denmark — [4]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) made out of $LiNbO_3$ are a versatile source of non-classical light [1]. Here, we report on recent progress in generating squeezed vacuum states in WGMRs via parametric down-conversion near the degenerate point. For that, we performed a detailed mode-analysis and improved the long-term stability of the setup to allow for stable operation above and below threshold. We also discuss the prospects of producing frequency combs and realizing more elaborate proposals such as enhanced optomechanical position detection via intra-cavity squeezing [2].

[1] J. U. Fürst et al., Phys. Rev. Lett. **106**, 113901(2011).
[2] V. Peano et al., Phys. Rev. Lett. **115**, 243603(2015).

Q 53.65 Thu 17:00 P OGs

Feedback cooling of an optically levitated silica nanosphere in a Michelson-Sagnac interferometer — •Manuel Reisenbauer, Ralf Riedinger, and Markus Aspelmeyer — Universität Wien, Vienna, Austria

A Michelson-Sagnac interferometer is well suited for the position readout of low reflectivity mechanical oscillators [1], as the non-interacting light leaves the interferometer through the bright port, while the reflected light interferes like in a Michelson interferometer, yielding a position dependent phase quadrature in the dark port. We show in a proof-of-principle experiment that by introducing two lenses in the interferometer mode, a dielectric nanoparticle can be trapped optically in one of the standing wave fringes of the Sagnac-mode near the focus. Feedback cooling of the particle is demonstrated, using the radiation pressure of an auxiliary laser beam.

Q 53.66 Thu 17:00 P OGs

Narrow-band single-photon source by resonant excitation of a nitrogen-vacancy center coupled to a microresonator — •Florian Böhm[1], Christoph Pyrlik[2], Jan Schlegel[2], Andreas Thies[2], Andreas Wicht[2], and Oliver Benson[1] — [1]AG Nanooptik, Humbodt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institut für Höchstfrequenztechnik, Berlin, Germany

Efficient and bright integrated solid-state single photon sources, preferably with narrow-bandwidth emission are a crucial prerequisite for future applications in quantum information science.

We report on our approach towards an integrated microresonator-enhanced single-photon source, consisting of nano-sized quantum emitters evanescently coupled to resonant photonic structures. In our proposed system we make use of single quantum emitters coupled deterministically [1] to a monolithic add-drop ring microresonator configuration. This hybrid system locally enhances the intensity of the excitation light and allows easy separation of the resonant excitation light from the emitted single photons via the two well-defined polarisations of the guided modes. Resonant excitation of the quantum emitters at the zero-phonon line promises a strong suppression of spectral diffusion and therefore a narrow spectral emission [2].

The proposed system has a narrow-bandwidth emission of single photons coupled to a single optical mode and is promising as a source e.g. in quantum information and quantum cryptography.

[1] Schell A.W., et al. (2011). Rev. Sci. Instrum., 82(7), 073709.
[2] Wolters J., et al. (2013). Phys. Rev. Lett., 110(2), 027401.

Q 53.67 Thu 17:00 P OGs

Efficient solid-state light-matter interfaces based on dielectric slot waveguides and diamond colour centers — •Martin Zeitlmair[1], Philipp Altpeter[1], Peter Fischer[1], Markus Weber[3], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Max-Planck-Institut für die Physik des Lichts, Erlangen

Future applications in applied quantum information science and ultrasensitive spectroscopy rely on efficient interaction between light and matter. Such light-matter interfaces require two key components: A waveguiding structure to control the propagation of photons and a quantum light source emitting single photons. Here, we present major progress towards a novel on-chip interface based on broadband dielectric slot waveguides for evanescent coupling of nanophotonic emitters and nitrogen-vacancy centers in nanodiamonds.

We choose Ta_2O_5 as a material platform due to its high dielectric contrast and low autofluorescence. By applying a lithographic top-down fabrication process, single-mode waveguides with low propagation losses of about 1dB/mm are created. A subsequent ion-beam milling process enables the production of air slots providing the strong confinement of optical waveguide modes, which should make high coupling efficiencies of optical waveguide structures possible. By choosing an optimised waveguide geometry coupling efficiencies over 50% for the whole spectrum of the NV-center can be expected.

Q 53.68 Thu 17:00 P OGs

Strong coupling between two optical $\lambda/2$ Fabry-Pérot resonators — •Achim Junginger[1], Felix Blendinger[2], Michael Metzger[2], Alexander Konrad[1], Marc Brecht[1], and Alfred J. Meixner[1] — [1]Institute of Physical and Theoretical Chemistry, University of Tübingen — [2]Fakulty Mechanical and Medical Engineering (MME), Furtwangen University

A $\lambda/2$ Fabry-Pérot resonator is made of two parallel mirrors and has a transmission maximum for light with a wavelength, corresponding to twice the mirror separation divided by the refraction index of the medium inside the resonator. We have investigated the resonance condition for a system of three parallel mirrors, separated by half an optical wavelength, while one outer mirror can be moved. For on axis illumination of the coupled resonators with white light, anticrossing of the wavelengths of the transmission maximum can be observed for the detuning of the adjustable resonator over the length of the fixed resonator. The occurrence of the anticrossing behavior can be adjusted when changing the thickness and therefore the reflectivity of the central silver mirror. With this experiment, we can model strong coupling with different coupling strengths.

Q 53.69 Thu 17:00 P OGs

Temperature dependent measurements of spin relaxation times of NV centers in nanodiamonds — •Lukas Antoniuk[1], Andreas Dietrich[1], Stefan Häussler[1], Kobinian Kottmann[1], Ilai Schwarz[2], Christoph Müller[1], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Institute for Theoretical Physics, Ulm University, D-89081 Ulm, Germany

Nitrogen-vacancy (NV) color centers in nanodiamonds (<100nm) are promising candidates for nanoscale sensing and for hyperpolarization techniques, which are based on the transfer of the NV center's electron spin polarization to surrounding nuclear spins. However, both applications are limited by the spin relaxation time of the NV centre spin, which is relatively short compared to NV centers in bulk diamond. The spin relaxation time is dominated by interactions with a bath of paramagnetic impurities on the diamond surface [1]. Here we present spin relaxation time measurements in nanodiamonds of different sizes over a broad range of cryogenic temperatures, which allow to gain a better understanding on the ongoing interactions. The nanodiamond size and therefore the distance from NV centres to the surface thereby determines the interaction strength and temperatures changes are influencing the dynamics in the surrounding bath.

[1] J.-P. Tetienne, et al. Phys.Rev. B. 87, 235436 (2013)

Q 53.70 Thu 17:00 P OGs

An optical nanofiber-based interface for single molecules — •Hardy Schauffert[1], David Papencordt[1], Sarah M. Skoff[1], Bernhard C. Bayer[2], and Arno Rauschenbeutel[1] — [1]Vienna Center for Quantum Science and Technology, Institute of Atomic and Subatomic Physic, Vienna University of Technology, Stadionallee 2, A-1020 Vienna, Austria — [2]Electron Microscopy Group, Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria

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 a high-intensity evanescent wave. An emitter brought close to the surface of the nanofiber has a large effect on 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 nano-crystal 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. In this way, we realize a fully fiber-integrated system that is scalable and may become a versatile constituent for quantum hybrid systems.

Q 53.71 Thu 17:00 P OGs

Creation of Color Centers in Diamond by Focused Ion Implantation — •Johannes Lang, Philipp Vetter, Boris Naydenov, and Fedor Jelezko — Institute for Quantum Optics, University Ulm, Germany

The color centers in diamond formed by a substitutional nitrogen or silicon and an adjacent vacancy (NV or SiV center) are amongst the most studied defects in diamond. They are promising candidates 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. The on demand creation of these color centers is required for the applications mentioned above [3].

Here, we present a home built, low energy, UHV ion implantation setup and show the creation of single, shallow (< 10 nm) color centers with well controllable properties regarding their implantation depth, density and position.

[1] M. W. Doherty et al., Physics Reports 528 1-45 (2013)
[2] C. Müller et al., Nat. Comm. 5 4703 (2014)
[3] J. Meijer et al., Appl. Phys. Lett. 87 261909 (2005)

Q 53.72 Thu 17:00 P OGs

Coherent control of free-electron beams on attosecond time scales — •Christopher Rathje, Katharina E. Priebe, Armin Feist, Sascha Schäfer, and Claus Ropers — IV. Physical Institute - Solids and Nanostructures, University of Göttingen, Germany

Ultrafast transmission electron microscopy (UTEM) is a recently developed approach to investigate dynamics with both nanometer spatial and femtosecond temporal resolution. Here, we use the highly coherent free-electron beam of our UTEM [1] to study inelastic electron-light scattering [2]. In particular, we manipulate the quantum state of single electrons using intense tailored light fields [3,4]. The optical near-field imprints a sinusoidal phase modulation on the electron wavefunction, which is manifest in a comb of sidebands in the electron kinetic energy distribution [3]. In a recent experiment [4], we demonstrated the quantum coherence and reversibility of this process by employing two spatially separated near-fields, such that the final quantum state sensitively depends on the relative near-field phase. Here, we describe our progress towards measuring the predicted self-compression of the initial wavefunction into a train of attosecond bursts [3]. The quantum coherent electron-light interaction is a promising approach for temporal structuring of free-electron beams with attosecond precision. [1] Feist et al., arXiv:1611.05022 (2016) [2] Barwick et al., Nature 462, 902 (2009) [3] Feist et al., Nature 521, 200-203 (2015) [4] Echternkamp et al., Nat. Phys. 12, 1000-1004 (2016)

Q 53.73 Thu 17:00 P OGs

Frequenzverdopplung in β-Bariumborat (β -BBO) unter Anwendung elliptischer Fokussierung in einem externen Resonator für den Einsatz zur Ionenstrahlkühlung — •Daniel Preissler, Daniel Kiefer, Thorsten Führer und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstr. 7, 64289 Darmstadt

Am ESR der GSI (Darmstadt, Deutschland) werden Experimente mit relativistischen, kalten Ionenstrahlen durchgeführt. Um die dafür nötige Reduktion der Impulsverteilung der Ionen zu erreichen [1], wurde ein Lasersystem bestehend aus einem ECDL, einem Faserverstärker und zwei aufeinanderfolgenden Frequenzverdopplungsstufen entwickelt, welches Dauerstrich-Strahlung im UV-Bereich emittiert [2]. Da der in der zweiten Frequenzverdopplungsstufe verwendete BBO-Kristall eine UV-induzierte Degradierung erfährt, wird ein neuer Resonator konstruiert, der eine elliptische Fokussierung in den Kristall ermöglicht. Dadurch kann einerseits eine höhere Konversionseffizienz, andererseits aber auch eine niedrigere Spitzenintensität erreicht werden [3], um die Degradierung zu verhindern. Im Beitrag werden Simulationen zum Aufbau des Resonators sowie der Stand der experimentellen Realisierung diskutiert.

[1] J. S. Hangst et al., Phys. Rev. Lett. 74, 4432-4435 (1995).
[2] T. Beck, Dissertation, TU Darmstadt (2015).
[3] A. Steinbach et al., Opt. Commun. 123, 207-214 (1996).

Q 53.74 Thu 17:00 P OGs

Q-switched Yb:YAG channel waveguide laser using low-dimensional carbon nanomaterials — •Sun Young Choi[1], Mi

Hye Kim[3], Fabian Rotermund[4], Christian Kränkel[1,2], and Thomas Calmano[1,2] — [1]Institut für Laser-Physik, Universität Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Germany — [3]Center for Quantum-Beam-based Radiation Research, KAERI, Republic of Korea — [4]Department of Physics, KAIST, Republic of Korea

Graphene and single-walled carbon nanotubes (SWCNTs) are frequently used for saturable absorbers which can be applied for short pulse lasers. Intrinsic nonlinear absorption in a broad spectral range and few ps response time of these materials guarantee good performance. Moreover, their relatively simple fabrication process provides flexibility and makes these devices suitable for integrated systems such as waveguide lasers. We demonstrate efficient pulsed Yb:YAG channel waveguide lasers using low-dimensional carbon nanomaterials. A 9 mm-long, fs-laser-inscribed Yb:YAG channel waveguide laser delivers stable Q-switched pulses around 1030 nm output wavelength utilizing graphene or SWCNT-coated output coupling mirrors. In this way, a maximum average output power of 80 mW and 79 ns pulse duration were obtained at a efficiency of up to 33% using a graphene-coated 20% output coupler under pumping with 285 mW from a laser diode. In additional experiments, atomically thin layered graphene was applied directly on the end-facet of the channel waveguide to achieve a compact and monolithic Q-switched waveguide laser system.

Q 53.75 Thu 17:00 P OGs

Efficient high repetition rate difference frequency generation in PPLN for MIR sum frequency microscopy — Christoph Kölbel, •Lukas Ebner, Martin Winterhalder, and Andreas Zumbusch — Universität Konstanz

High repetition rate mid-infrared (MIR) optical parametric oscillators (OPOs) are used for sum frequency generation (SFM) microscopy [1]. In this work, we present an alternative cost and conversion efficient processes to generate ultrashort, bandwidth limited MIR-Laser pulses via difference frequency generation (DFG) in periodically poled Lithium Niobate (PPLN). The use of a synchronised 80 MHz dual output fs-Laser source with a fixed output at 1037 nm and a tunable (680-1300 nm) output allows the generation of MIR-Light between (3,1-5,5 μm). Based on this source and a collinear excitation geometry we present first sum frequency generation (SFM) microscopy images.

[1]. Raghunathan, V. et al., Optics Letters, 36(19), 3891-3893 (2011).

Q 53.76 Thu 17:00 P OGs

Autonomously operating laser systems for quantum sensors in space - from sounding rockets to small satellites — •Aline Dinkelaker[1], Max Schiemangk[1], Vladimir Schkolnik[1], Andrew Kenyon[1], Markus Krutzik[1], Achim Peters[1,2], and The KALEXUS MAIUS and LASUS Teams[1,2,3,4,5,6,7] — [1]Humboldt-Universität zu Berlin — [2]FBH Berlin — [3]JGU Mainz — [4]LU Hannover — [5]U Bremen — [6]U Hamburg — [7]Menlo Systems GmbH

Laser systems are key technology for fundamental and applied physics experiments on space platforms - from quantum optical communication to tests of general relativity with quantum sensors. Such laser systems have to fulfill demanding requirements on frequency stability and output power, while being compact and rugged in order to operate reliably after launch into space. As interaction from ground will be limited, automated experiment control is desired. To demonstrate their functionality in space, we have flight-proven different laser system for atomic physics experiments on sounding rockets: the KALEXUS and LASUS experiments are technology demonstrators for frequency stabilized micro-integrated extended cavity diode lasers (ECDLs) at rubidium and potassium wavelengths. We now aim to test laser systems on small satellites where radiation effects, UHV compatibility and long term stability can be studied. We present results of our sounding rocket missions with an outlook on future laser system experiments on small satellites. This 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 50WM1237/1345/1132 .

Q 53.77 Thu 17:00 P OGs

Zerodur-based optical systems for dual-species atom interferometry in space — •Moritz Mihm[1], Kai Lampmann[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

The precision of inertial measurements has been tremendously increased with the advent of cold atom-based interferometers. Space missions which allow higher precision of such instruments rely on the laser system, dedicated to cool and manipulate the atoms.

Subsequent to successful previous sounding rocket missions, we report on a laser system for rocket missions performing dual-species atom interferometry with BECs. Core elements of the laser system are optical benches and fiber-optical elements used on the one hand to distribute, overlap and switch the laser beams and on the other hand to stabilize the laser frequencies. In order to withstand the harsh conditions during flight, we use the glass ceramic Zerodur providing high mechanical and thermal stability. A Zerodur-based test bench for the qualification of new components has been assembled, characterized and tested under flight conditions. Currently, the flight hardware is built and characterized prior to integration.

MAIUS is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50 WM 1133 and 50 WP 1433.

Q 53.78 Thu 17:00 P OGs

Ionisationsstudie mit Beryllium — •Sebastian Wolf, Frederic Wagner, Dominik Studer, Klaus Wendt und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Einfach geladene Beryllium Ionen sind für sympathetisches Kühlen in Ionenfallenexperimenten hervorragend geeignet [1,2]. Für die Ionisation von neutralem Beryllium kann die Elektronen-Ionisation verwendet werden, führt jedoch in Mikrofallen zu unkontrollierten Aufladungen. Für die resonante Photoionisation wird ein kommerzielles vervierfachtes cw-Diodenlasersystem verwendet [3]. Wir untersuchen alternative Ionisationsverfahren die auf gepulsten Laserlichtquellen beruhen: Zum Einsatz kommen eine kostengünstige Nd:YAG Laserquelle, bei der die 2. (10 ns, 15 mJ) bzw. die 4. (10 ns, 2 mJ) Harmonische über einen nicht-resonanten Multi-Photonenprozess ins Kontinuum ionisiert, und alternativ die 4. (100 ns, 1 μJ) Harmonische eines gepulsten Ti:Sa-Lasers um in einem resonanten Prozess bei 235 nm zu ionisieren.

[1] P. Perez et al., Class. Quantum Grav. 29, 184008 (2012)
[2] T. Murböck et al., Phys. Rev. A 94, 043410 (2016)
[3] Hsiang-Yu Lo et al., Appl. Phys. B 114:17-25 (2014)

Q 53.79 Thu 17:00 P OGs

Dispersion engineering of integrated photon pair sources at telecommunication wavelength — •Mahnaz Doostdar, Matteo Santandrea, Vahid Ansari, Christof Eigner, Raimund Ricken, Helge Rütz, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Parametric Down Conversion (PDC) is widely used as the source of pairs of single photons in quantum information science. The properties of this nonlinear optical process, however, have to be tailored to generate the desired state. Here we focus on engineering the dispersion properties of the PDC process to generate spatially single-mode and spectrally decorrelated PDC states at telecommunication wavelengths. Periodically poled potassium titanyl phosphate (PPKTP) can provide those required features. Here we present our recent advances in fabrication of such waveguided PDC sources.

Q 53.80 Thu 17:00 P OGs

Low Noise Fast Multichannel Arbitrary waveform Generator for the Segmented Trap — •Vidyut Kaushal, Heinz Lenk, Ulrich G. Poschinger, and Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Noisy trap electrode potentials have always been a fundamental source of decoherence in ion-trap based studies of quantum systems. Scaling up the number of electrode in modern segmented traps, this becomes even more challenging, as fast and simultaneous real-time control of the segment voltages with high signal integrity and sampling rate is required. We present a functional design of low noise(<-70dbm), high precision, fast AWG featuring 80 independent analog channels. Additionally, the delay between consecutive samples can be controlled in steps of 20 ns, resolving typical trap oscillation periods - a crucial feature for the control of fast shuttling operations [1,2]. The output voltage range of +/- 40 V allows for tight confinement of trapped ions and compensation of signal distortion.

We describe the details of the architecture and thorough characterization of the relevant signals.The implementation of a toolset of shuttling operations for scalable quantum computing is shown. We also discuss future extensions towards a complete real-time control system including feedback capabilities.

[1] A. Walther et al., PRL 109, 080501 (2012)
[2] T. Ruster et al., PRA 90, 033410 (2014)

Q 53.81 Thu 17:00 P OGs

Modified dipole-dipole interaction and dissipation in an atomic ensemble near a surface — •Ryan Jones and Beatriz Olmos — School of Physics and Astronomy, The University of Nottingham, University Park, NG7 2RD, United Kingdom

Particularly in the area of imaging, surfaces of different materials and shapes are used to manipulate the electromagnetic field experienced atoms in order to change their spontaneous decay rate. As well as interference effects one can manipulate the system in other ways, for example in a metal the presence of surface plasmon polaritons can also drastically change how the system decays.

Relatively little is known about how surfaces affect systems whose behavior is collective. Such effects, including a coherent dipole-dipole interaction (photon exchange) and collective decay, exist in ensembles of two-level atoms with atomic separations that are much smaller than the transition wavelength. These systems have become increasingly relevant in recent years as developments in atomic cooling and trapping have made them experimentally feasible.

In this work, through a Green's tensor formalism we investigate how collective properties are modified when a cold dense system is placed in proximity to surfaces of different materials. By scanning over a range of parameters, we identify regimes in which the collective behaviors of the system are modified considerably.

These results will be of value to current and future experiments investigating the dipole-dipole interaction, where surface interactions can provide an extra degree of control over the system.

Q 53.82 Thu 17:00 P OGs

Entangled photons triplets, produced via third order parametric down conversion in bulk materials — Cameron Okoth[1], •Andrea Cavanna[1], and Maria Chekhova[1,2] — [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

Parametric down conversion (PDC) is a highly developed research field and is now commonly used in several areas of optics. Despite this PDC has only been observed when one considers the second order susceptibility term. We intend to experimentally observe seeded generation of triple photons, where the seed is collinear with the pump. In this way the entire process is can be thought as analogous to standard PDC but with the efficiency changed by a factor of $\chi^{(2)}/(\chi^{(3)}E_{seed})$, where E_{seed} is the seed field. Many of the recent attempts to observe triplet photons have been fiber based. Although fibers have some advantages over bulk materials, there are still many reasons to include crystals as promising candidates in which to generate triplet photons: high effective cubic susceptibility, no lowered efficiency due to modal overlap and tunable phase matching to name but a few. In our work we concentrate on calcite but can be readily extended to rutile, KTP etc.

Q 53.83 Thu 17:00 P OGs

Relativistic Quantum Information Experiments with a Geostationary Satellite — •Ömer Bayraktar[1,2], Kevin Günthner[1,2], Imran Khan[1,2], Dominique Elser[1,2], 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.

The current development in satellite-based quantum communication pushes quantum physics experiments into the relativistic regime [1]. While a theoretical description in terms of quantum field theory in curved space-time (or relativistic quantum information) is in progress, experimental evidence for the predictions are not existing yet [2]. In addition, the impact of relativistic effects on long-distance quantum communication needs to be quantified. We investigate potential realization of relativistic quantum information experiments with a satellite in the geostationary Earth orbit. Thereby, we aim to complement quantum field theory in curved space-time with experimental evidence and explore possible limitations of satellite-based quantum communication.

[1] D. Rideout *et al.*, Class. Quantum Gravity **29**, 224011 (2012).
[2] R. Howl *et al.*, arXiv:1607.06666 (2016).

Q 53.84 Thu 17:00 P OGs

2D layer of dipolarly coupled nuclear spins for a solid state quantum simulator — •Nikolas Tomek[1], Paz London[2], Timo Weggler[1], Kohei Itoh[3], Hideyuki Watanabe[4], Boris Naydenov[1], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, Ulm 89081, Germany — [2]Department of Physics, Technion, Israel Institute of Technology, Haifa 32000, Israel — [3]Department of Applied Physics and Physico-Informatics, Keio University, Hiyoshi, Yokohama, JapanDepartment of Applied Physics and Physico-Informatics, Keio University, Hiyoshi, Yokohama, Japan — [4]Natl Inst Adv Ind Sci & Technol, Res Inst Elect & Photon, Tsukuba, Ibaraki 3058562, Japan

Understanding and controlling a strongly correlated quantum many-body system is an essential step towards a large scale quantum simulator. Such a device would enable access to nonequilibrium dynamics of large systems where state of the art numerical simulations are quickly reaching their limits. To reach this goal we are studying a ^{12}C-enriched bulk diamond containing a few nanometer thick layer of ^{13}C nuclei. In order to access these nuclear spins we utilize nitrogen-vacancy (NV) centers grown into the diamond around the layer. The system stands out due to exceptional long coherence times even at room temperature. To expose the dipolar coupling inside the ^{13}C layer we are conducting experiments to show diffusion of spin polarization from one NV to another. A microwave assisted superresolution imaging reveals a distance between the NVs below 50 nm. Furthermore we will use this system to investigate multi-quantum coherences inside the nuclear spin lattice.

Q 53.85 Thu 17:00 P OGs

Pulse-to-pulse measurements on a broadband PDC source — •Thomas Dirmeier[1,2], Imran Khan[1,2], Georg Harder[3], Vahid Ansari[3], Johannes Tiedau[3], Ulrich Vogl[1,2], Gerd Leuchs[1,2,4], Christoph Marquardt[1,2], and Christine Silberhorn[3] — [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]Lehrstuhl für Angewandte Physik, Universität Paderborn, Warburgerstr. 100, 33098 Paderborn — [4]Department of Physics and Max Planck - University of Ottawa Centre for Extreme and Quantum Photonics, University of Ottawa, Canada

PDC sources embedded in ppKTP waveguides have been shown to be stable sources of squeezed vacuum states with a broad versatility in the spectral mode structure. Recently, it has been demonstrated that by applying high pump powers, states with high mean photon numbers can be generated and measured [1], translating into high squeezing values.

In our work, we focus on the application of this type of source in the continuous-variable context, mainly focusing on the measurement of squeezed vacuum states in both, the spectral single and multimode case. We show the progress on the pulse-resolved homodyne detection in this system and its combination with photon counting measurements in quantum information protocols.

[1] G.Harder et.al.,Phys. Rev. Lett. 116, 143601 (2016)

Q 53.86 Thu 17:00 P OGs

Non-local currents in discrete planar Systems with spatial local symmetries — •Malte Röntgen, Christian Morfonios, and Peter Schmelcher — Zentrum f. Optische Quantentechnologien, Luruper Chaussee 149, 22761 Hamburg

Local symmetries are spatial symmetries that are only present in a spatially finite subdomain of a system. Contrary to global symmetries, the operators Σ_L describing local symmetries generally do not commute with the system's Hamiltonian and one cannot choose the eigenstates to be symmetric under Σ_L. We show that it is nevertheless possible to gain knowledge about the structure of a system's eigenstates, provided it possesses local symmetries. We use a new framework of so-called non-local currents which has recently been developed for one-dimensional discrete systems and extend it to two dimensions and the case of topological asymmetries. These asymmetries may be present if the system has a non-uniform connectivity. The framework may then be used as a basis for further investigations of the impact of local symmetries. In this paper, we investigate two special subsystems that feature local symmetries, so-called closed-loops and open ended chains. We use our framework to show that the all or some of the amplitudes of eigenstates within these subsystems are related to each other by a constant. Our results show that local symmetries in discrete systems may provide new insights into the behaviour of complex systems.

Q 54: Ultracold atoms and BEC - V (with A)

Time: Friday 11:00–13:00 Location: N 1

Q 54.1 Fri 11:00 N 1

Quantum Galvanometer with ultracold atoms — •Carola Rogulj, Peter Federsel, Malte Reinschmidt, Lukas Gussmann, Andreas Günther, and József Fortágh — Physikalisches Institut, Auf der Morgenstelle 14, D-72076 Tübingen

Hybrid quantum systems are engineered to combine properties and advantages of two quantum systems. Heading for novel quantum technologies, ultracold atoms and nanomechanical resonators are promising candidates for quantum information processing. Ultracold atoms and degenerate quantum gases can be very precisely manipulated and provide long coherence times, which makes them for example well suited quantum memories. Nanomechanical oscillators can not only be functionalized to allow for sensitive force detection, but can also be cooled down to their quantummechanical ground state. In my talk, I will show a Quantum Galvanometer scheme and its experimental realisation, where an oscillating nanomechanical resonator carrying electrical current is brought to interaction with a Bose Einstein condensate of ^{87}Rb atoms. This is achieved by means of an atomchip with magnetic conveyor belt. In our case, the resonator consists of a gold coated silicon nitride beam. It creates a fluctuating electromagnetical field which serves as output coupler for an atom laser. We have developed a state and energy selective single atom detection scheme that allows to observe temporal correlations of this atom laser. The magnetomechanically coupled hybrid system will thus enable us to measure the statistics of current fluctuations in a setup that is capable of resolving quantum properties of electrical current.

Q 54.2 Fri 11:15 N 1

A deterministic ion source based on ultracold atoms — •Cihan Sahin, Jens Benary, Philipp Geppert, Andreas Müllers, and Herwig Ott — Technische Universität Kaiserslautern

An ion source with minimal energy spread and deterministic emission has many applications in basic research and technical applications including surface spectroscopy, ion implantation or ion interferometry.

We have developed an ion source based on ^{87}Rb atoms confined in a magneto-optical trap. The atoms are ionized with a three photon scheme, built-up of infrared lasers. This results in a minimal energy transfer to the ionization fragments and reduces the electron background from the photoelectric effect.

To detect the electrons and ions, we currently use channel electron multipliers (CEM). The electron, registered within a few ns after ionization, is utilized for the deterministic operation of the ion source. The much slower ions are controlled by a gate electrode, which is by default blocking them. If an electron is registered, the gate is opened for a short time to let the corresponding ion pass.

Currently, we are able to operate the source with an ion rate from a few to 10^4 s^{-1} in gated mode, and 10^6 s^{-1} without gate operation. We discuss the results obtained so far including the statistical properties of our source.

In a next step, the ion CEM will be replaced with a position sensitive detector for ion momentum spectrocopy. Additionally, an adaptive ion optics upgrade may be used to manipulate ion trajectories in real time and allow for aberation corrections.

Q 54.3 Fri 11:30 N 1

Ultracold electron source from a MOT studied by ToF-microscopy — •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 report on the first results of the application of cold Cs atoms as a monochromatic (photo-) electron source obtained with time-of-flight momentum microscopy. Such sources provide an electron beam for high energy resolution (meV-range) spectroscopic electron microscopy [1]. The experimental set-up consists of a magneto-optical trap with Cs atoms, ionization lasers, lens system of the ToF-microscope and delayline detector [2]. Last two allow mapping of 3D spectral function I(k_x, k_y, t). The ToF study of photoelectron dynamics was performed using pulsed pico- and femtosecond lasers for ionization above or just at the ionization threshold. In the first case a picosecond pulsed LD @ 375 nm was used for the direct ionization from $6p_{3/2}$. In the second case a LD @ 1470 nm (excitation $6p_{3/2} \rightarrow 7s_{1/2}$) was used in combination with a Ti-sapphire laser @ 750-800 nm (ionization from the $7s_{1/2}$). Consequently, varying the initial photoelectron energy in the range from 5 meV up to 860 meV above the ionization limit gives the opportunity to find optimal conditions to get the best electron beam parameters - time and energy spread, emittance, brightness and focusing.

Funded by ANR/DFG HREELM

[1] M. Kitajima et al., Europ. Phys. J. D 66, 130 (2012). [2] A. Oelsner et al., J. Electron Spectrosc. 178-179, 317 (2010).

Q 54.4 Fri 11:45 N 1

Realization of uniform synthetic magnetic fields by periodically shaking an optical square lattice — Charles Creffield[1], •Gregor Pieplow[1], Fernando Sols[1], and Nathan Goldman[2] — [1]Departamento de Física de Materiales, Universidad Complutense de Madrid, E-28040 Madrid, Spain — [2]CENOLI, Faculté des Sciences, Université Libre de Bruxelles (U.L.B.), B-1050 Brussels, Belgium

A powerful method to create effective magnetic fields is to shake a lattice of cold gases trapped in an optical lattice. Typically such schemes produce space-dependent effective masses and non-uniform flux patterns. In this work we try to tackle this problem by proposing several lattice shaking protocols, theoretically investigating their associated effective Hamiltonians and their quasienergy spectra. This allows the identification of novel shaking schemes, which simultaneously provide uniform effective mass and magnetic flux, with direct implications for cold-atom experiments and photonics.

Q 54.5 Fri 12:00 N 1

Cavity-assisted measurement and coherent control of collective atomic spin oscillators — •Nicolas Spethmann[1,2], Jonathan Kohler[2], Sydney Schreppler[2], and Dan Stamper-Kurn[2,3] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Department of Physics, University of California, Berkeley, CA 94720, USA — [3]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

I will present experiments of continuous measurement and coherent control of the collective spin of an atomic ensemble trapped and evolving in a high-finesse cavity. We employ autonomous optical feedback onto the atomic spin dynamics, conditioned by the cavity spectrum, as a feedback mechanism to stabilize the spin in either its high- or low-energy state. We measure the effective spin temperature from the asymmetry between the Stokes and anti-Stokes sidebands. We demonstrate that such a feedback-stabilized spin ensemble remains in a nearly pure quantum state, in spite of measurement back-action due to the continuous interaction with the probe field. Here, the high-energy spin state corresponds to a state with negative effective temperature. The system realized in our work paves the way for applications in the quantum regime, as for example quantum-limited, phase-preserving spin amplifiers or coherent quantum noise cancellation techniques.

Q 54.6 Fri 12:15 N 1

Sudden and Slow Quenches into the Antiferromagnetic Phase of Ultracold Fermions — Monika Ojekhile[1], •Robert Höppner[1], Henning Moritz[2], and Ludwig Mathey[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany

We propose a method to reach the antiferromagnetic state of two-dimensional Fermi gases trapped in optical lattices: Independent subsystems are prepared in suitable initial states and then connected by a sudden or slow quench of the tunneling between the subsystems, while subjecting the system to a time-dependent staggered magnetic field. Examples of suitable low-entropy subsystems are double wells or plaquettes, which can be experimentally realised in Mott insulating shells using optical super-lattices. Expanding on previous work reported in Ref. [1], we now investigate the effect of finite quench times and different quench protocols on the final state energy using a the quantum Heisenberg model of a finite system.

[1] Zeitschrift für Naturforschung A., Vol. 71, Issue 12, Pages 1143-1150

Q 54.7 Fri 12:30 N 1

Measuring Correlations in a Double Well with Single-Atom Imaging — •Vincent M. Klinkhamer, Andrea Bergschneider, Jan Hendrik Becher, Philine L. Bommer, Justin F. Niedermeyer, Gerhard Zürn, Philipp M. Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

We deterministically prepare quantum states of two interacting Lithium atoms in an optical double-well potential. To recover the occupation number on the sites, we detect individual atoms with our new spin-resolved fluorescence imaging. However, interesting properties such as the symmetry between particles cannot be measured in this way. Therefore we measure the momenta of the individual atoms after time-of-flight expansion. This allows us to determine the correlations between two atoms with high contrast.

Q 54.8 Fri 12:45 N 1

Scaling of a long-range interacting quantum spin system driven out of equilibrium — •Stephan Helmrich, Alda Arias, and Shannon Whitlock — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Complex systems are often found to exhibit unexpectedly simple scaling laws that can signal new physical regimes or universal relations between otherwise very different systems. Although this provides a powerful tool for characterising systems close to equilibrium, there are only few known examples where scaling behavior can be found in dynamical settings. Here we demonstrate power-law scaling in a well-controlled quantum spin system driven out of equilibrium [1]. This enables us to reconstruct the non-equilibrium phase diagram of the system and to identify dissipation-dominated, driving-dominated and interaction-dominated regimes. Comparing the measured scaling laws with kinetic Monte Carlo simulations we uncover the microscopic origin of the observed scalings. This opens up a new means to study and classify quantum systems out of equilibrium and extends the domain where scale-invariant behavior can be found.

[1] S. Helmrich, A. Arias, and S. Whitlock. arXiv:1605.08609, 2016

Q 55: Quantum Computing II

Time: Friday 14:30–16:15 Location: P 2

Q 55.1 Fri 14:30 P 2

Estimating the error of a quantum simulator by additional measurments — Iris Schwenk, Sebastian Zanker, Jan Reiner, Juha Leppakangas, and •Michael Marthaler — Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany

We study an analog quantum simulator coupled to a reservoir with a known spectral density. The reservoir can cause decay and decoherence. The quantum simulator is used to measure an operator average, which can not be calculated using any classical means. Since we can not predict the result it is difficult to know the effect of the environment. Especially, we can not know whether the perturbation is small or if the actual result of the measurement is in fact very different from the ideal system we intend to study. We show that it is possible to use a perturbative approach which contains only measurable quantities to estimate the size of the error.

Q 55.2 Fri 14:45 P 2

Energy localization ensures robustness of digital quantum simulation — •Philipp Hauke[1,2], Markus Heyl[3], and Peter Zoller[1,2] — [1]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck — [2]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck — [3]Max-Planck-Institut fuer Physik komplexer Systeme, D-01187 Dresden

Following Lloyds seminal work from 1996, the Trotter error of digital quantum simulation (DQSs) is usually assumed to diverge with simulated time and particle number. This is true if one is interested in the correctness of the full time-evolution operator. In quantum simulation, however, the quantities of interest are typically few-body observables. Understanding the DQS as a periodically driven system, we demonstrate that, once the Trotter step is sufficiently small, the error of few-body observables remains bounded even for large systems and for arbitrarily long times. This is ensured for all systems that display energy localization. In that case, a sharp transition exists into a regime where Trotter errors in local observables become perturbative. Even in systems where energy localization does not exist, we argue that the DQS deteriorates only logarithmically with time. As these findings show, digital quantum simulation can be exponentially better than usually stated, as long as one is concerned with few-body observables.

Q 55.3 Fri 15:00 P 2

Scalable architecture for quantum simulation and quantum computation with more than 150 individually addressable qubits — •Dominik Schäffner, Daniel Ohl de Mello, Tilman Preuschoff, Lars Kohfahl, Jan-Niklas Schmidt, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Efficient quantum simulation and quantum information processing requires scalable architectures that guarantee the allocation of large-scale qubit resources. In our work, we focus on the implementation of multi-site geometries based on microfabricated optical elements. This approach allows us to develop flexible, integrable and scalable configurations of multi-site focused beam traps for the storage and manipulation of single-atom qubits and their interactions [1].

We give an overview on the investigation of ^{85}Rb atoms in two-dimensional arrays of more than 400 individually addressable dipole traps featuring trap sizes and a tunable site-separation in the single micrometer regime. Furthermore, we experimentally demonstrate single-atom quantum registers with more than 150 occupied sites and single-site resolved addressing of single atom quantum states in a reconfigurable fashion. We will discuss progress in introducing Rydberg based interactions and present prospects of our platform for the investigation of many-body physics.

[1] For an overview see: M. Schlosser, S. Tichelmann, J. Kruse, and G. Birkl, Quant. Inf. Proc. **10**, 907 (2011).

Q 55.4 Fri 15:15 P 2

Continuous-Variable Instantaneous Quantum Computing is hard to sample — Tom Douce[1,2], Damian Markham[1], Elham Kashefi[1], Eleni Diamanti[1], Thomas Coudreau[2], Perola Milman[2], Peter van Loock[3], and •Giulia Ferrini[2,3] — [1]Lip6, UPMC-Sorbonne Universités, 4 Place Jussieu, 75005 Paris, France — [2]Laboratoire Matériaux et Phénomènes Quantiques, Sorbonne Paris Cité, Univ. Paris Diderot, CNRS UMR 7162, 75013, Paris, France — [3]Institute of Physics, Johannes-Gutenberg Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Instantaneous Quantum Computing (IQP) is a sub-universal class of quantum circuits composed of Pauli-X eigenstates, gates diagonal in the Pauli-Z basis, and Pauli-X measurements [1]. We translate this class of circuits to Continuous-Variables (CV). Using the correspondence between universal sets of gates [2], we define CV IQP circuits as composed of input momentum-squeezed states, gates diagonal in position and homodyne momentum measurements. We analyse their computational power by studying post-selected circuits [1], and we prove that CV IQP circuits are hard to sample [3]. In order to deal with post-selection we consider finite resolution homodyne detectors. Finite squeezing in the input squeezed states is treated by adding to the model ancillary GKP states and by relying on a GKP encoding of quantum information [4].

[1] M. J. Bremner, R. Josza, and D. Shepherd, Proc. R. Soc. A 459, 459 (2010). [2] M. Gu et al, PRA 79, 062318 (2009). [3] T. Douce et al, arXiv:1607.07605 (2016). [4] N. C. Menicucci, PRL 112, 120504 (2014).

Q 55.5 Fri 15:30 P 2

Towards all optical quantum computing with single molecules — •Mohammad Rezai, Jörg Wrachtrup, and Ilja Gerhardt — Universität Stuttgart 3. Physikalisches Institut

Single quanta of light known as photons are the key element for quantum communication of the future. One source, organic dye molecules, can be chemically designed to cover the full visible spectrum. They can simultaneously act as both a high flux and an extremely narrow-band single photon source [1]. Their spectral line-width in the range of 10-20MHz is lifetime limited, and their indistinguishability is high. For quantum hybridization experiments with atomic vapors, we use dibenzanthanthrene C30H16 which matches spectrally well with sodium D-line transitions around 589nm. This allows for spectral Faraday filtering against unwanted light, e.g. caused by the source of excitation [2]. This contributes to the single photon's indistinguishability, which is measured to be close to unity. Furthermore, we use this to realize a delayed-choice quantum eraser experiment based on photons resonant with sodium.

[1] - P. Siyushev et al., Nature, 2014, 509, 66-70 [2] - W. Kiefer et al., Scientific Reports, 2014, 4, 6552

Q 55.6 Fri 15:45 P 2

Implementing single qubit gates using RSFQ pulses — •Per J. Liebermann and Frank K. Wilhelm — Universität des Saarlandes, Saarbrücken

Rapid single flux quantum (RSFQ) pulses are a highly viable candidate for the on-chip generation of control pulses for quantum computers based on Josephson devices. With a switching time in the picoseconds range it is possible to implement fast quantum gates [1]. We show that RSFQ pulses can drive high-fidelity single-qubit rotations in leaky transmon qubits, if the sequence of these restricted digital pulses is suitably optimized compared to an evenly spaced pulse train [2]. Genetic algorithms are used to converge to gate control precision compatible with the requirements of fault tolerant quantum computing. RSFQ shift registers are essential to perform the optimized sequence, limiting the reachable set of gates in a single shot. Timing jitter of the pulses is considered as well, showing the robustness of the optimized sequence. This makes the underlying RSFQ pulse platform an attractive candidate for an integrated control layer in a quantum processor.

[1] R. McDermott and M.G. Vavilov, Phys. Rev. Appl. 2, 014007 (2014)

[2] P.J. Liebermann and F.K. Wilhelm, Phys. Rev. Appl. 6, 024022 (2016)

Q 55.7 Fri 16:00 P 2

Deterministische Einzel-Ionen Implantation zur Erzeugung von NV-Zentren — •Karin Groot-Berning[1,2], Georg Jacob[2], Christian Osterkamp[3], Sebastian Wolf[2], Boris Naydenov[3], Fedor Jelezko[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]Universität Ulm, Institut für Quantenoptik, Albert-Einstein-Allee 11, 89081 Ulm, Germany

Wir berichten über die erfolgreiche deterministische Implantation einzelner Stickstoff Ionen zur Erzeugung von NV-Zentren. Hierfür wurde auf der Grundlage einer linearen Paulfalle eine Einzelionenquelle realisiert. Um einzelne ${}^{15}N_2^+$ Ionen in die Falle zu laden, werden diese aus einem istopenreinen Reservoir ionisiert, gefangen und durch ${}^{40}Ca^+$ Ionen sympathetisch gekühlt. Mit einer Extraktionsspannung von 5.9 keV werden die Ionen aus der Falle beschleunigt. Dabei wird das zu implantierende N_2^+ Ion vom Calcium Ion getrennt und durch eine elektrostatische Einzellinse auf die Probe fokussiert [1].

Um die Herkunft der Zentren aus der deterministischen Implantation nachzuweisen, verwenden wir gepulste ODMR-Spektroskopie mit welcher die Hyperfeinaufspaltung des ^{15}NV Zentrums (Kernspin I=1/2) gemessen werden kann. Zudem berichten wir über die Kohärenzzeiten dieser NV-Zentren und über Perspektiven zur Bildung von optischaktiven Zentren in Festkörpern mit hoher Effizienz.

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

Q 56: Optomechanics II

Time: Friday 14:30–15:45 Location: P 4

Q 56.1 Fri 14:30 P 4

Stable Zerodur optical benches for space applications — •Ioannis Drougkakis[1,2], Konstantinos Mavrakis[1,2], Konstantinos Poulios[1], Dimitris G Papazoglou[1,2], and Wolf von Klitzing[1] — [1]Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas, P.O. Box 1527, 71110, Heraklion, Greece — [2]Department of Material Science and Technology, University of Crete, P.O. Box 2208, 71003, Heraklion, Greece

A large number of optical systems used in space applications, require stable optical benches that are extremely robust, reliable and efficient. A major challenge in these applications is coupling light into single mode optical fibers after having traversed a number of active and passive optical elements. This leads to high level of complexity for the benches and for the subcomponents used. As a consequence of trade-offs between robustness, complexity, reliability and constrains in manufacturing, coupling efficiencies lie typically from 50% to 80% at the cost of an increased complexity of their sub-components and procedures. Here we report a novel scheme, which allows precise beam-steering for fiber-free space-fiber systems on a Zerodur breadboard using optical wedges and flats. Our approach greatly reduces the precision required for the sub-components as well as the complexity of the fiber couplers used. We present an in-depth theoretical treatment of the optical scheme, using both analytical and numerical simulations. We corroborate the results of the simulations with preliminary tests performed.

Q 56.2 Fri 14:45 P 4

THz radiation emission by phonon-polariton coupling in a semiconductor microcavity — •Katharina Rojan[1,2,3], Giovanna Morigi[3], Maxime Richard[4,5], and Anna Minguzzi[1,2] — [1]Université Grenoble Alpes, LPMMC, Grenoble, France — [2]CNRS, LPMMC, Grenoble, France — [3]Theoretische Physik, Universität des Saarlandes, Saarbrücken, Germany — [4]Université Grenoble Alpes, Institut Néel, Grenoble, France — [5]Université Grenoble Alpes, Institut Néel, Grenoble, France

We suggest a scheme to generate THz radiation emission out of a semiconductor microcavity in the strong coupling regime. For this purpose we consider a model of interacting excitons, photons, and phonons which we describe by coupled Heisenberg-Langevin equations. We investigate the conditions necessary to achieve and optimize the THz emission and analyse the characteristics of the emitted photons. Furthermore we discuss a possible experimental realization using state-of-the-art semiconductor microcavities.

Q 56.3 Fri 15:00 P 4

Two dimensional optomechanical crystals for quantum optomechanics — •Hannes Pfeifer[1], Greg MacCabe[2,3], Hengjiang Ren[2,3], and Oskar Painter[2,3] — [1]MPI for the Science of Light, Erlangen, Germany — [2]Kavli Nanoscience Institute, California Institute of Technology, Pasadena, USA — [3]Institute for Quantum Information and Matter and Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology, Pasadena, USA

Cooling of nanomechanical resonators to their motional ground state triggered recent achievements like non-classical mechanical state preparation or coherent optical to microwave photon conversion. Implementations through optomechanical crystal (OMC) resonators use co-localization of optical and acoustic modes in a patterned device layer of a silicon-on-insulator (SOI) chip. Their operation at small thermal mechanical mode occupations and mechanical Q-factors $\gtrsim 10^6$ requires pre-cooling to millikelvin temperatures, where even weak optical absorption induces unfavorable local heating. Commonly used one-dimensional nanobeam OMC resonators have significantly smaller thermal connectivity to the cool environment and reduced robustness against undesired heating than their two-dimensional counterparts. A drawback of 2D OMCs were their complex fabrication and weaker interaction of acoustic and optical modes. Here, we present a modified 2D OMC cavity that exhibits coupling strengths comparable to the previous nanobeams and reduces the complexity for nanofabrication compared to other 2D OMCs. It uses a mechanical mode at 11 GHz and creates a high Q optical cavity at telecom wavelengths.

Q 56.4 Fri 15:15 P 4

Novel approaches to optomechanical transduction — •Ondrej

Cernotik and Klemens Hammerer — Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover

In recent years, mechanical oscillators received attention as a promising tool for frequency conversion between microwaves and light. A general, bidirectional transducer with high efficiency is still far from reach of current technology; finding new strategies for optomechanical transduction allows us to relax the requirements and bring these systems closer to an experimental realization. An interesting example is generation of entanglement between two superconducting qubits using measurement and postselection. Here, the mechanical oscillators interacts directly with the superconducting transmon qubit in such a way that it feels a qubit-state dependent force. This force can then be read out using a cavity field; reading out two such systems sequentially realizes an effective total spin measurement. Starting from a suitable initial state and employing postselection, entanglement can be generated. Another interesting approach is to use an array of optomechanical transducers in which the output fields of one transducer are fed into the input of the next. The periodicity of the array results in a joint dispersion relation for the propagating microwave and optical fields. The resulting structure can be used to control the conversion bandwidth and forward and backward scattering.

Q 56.5 Fri 15:30 P 4

Collective atom-light interactions in an atom-optomechanical system — •Aline Faber[1], Tobias Kampschulte[2], Niels Lörch[1], Klemens Hammerer[3], and Philipp Treutlein[1] — [1]Universität Basel, Departement Physik — [2]Universität Ulm, Institut für Quantenmaterie — [3]Universität Hannover, Institut für theoretische Physik

Collective effects in atomic ensembles originating from the dispersive atom-light interaction have been observed in optical cavities but are not well studied in free space systems.

Here we report on an experiment with our hybrid atom-membrane system in which light-mediated atom-atom interactions in a free space ensemble strongly influence the atom-membrane dynamics. In our system the fundamental vibration of a Si_3N_4 membrane is coupled to the motion of atoms in an optical lattice over a macroscopic distance via the lattice light itself. Collective effects between the atoms lead to a significant phase delay in the atomic back-action onto the lattice light which induces an instability in the coupled system if the coupling is large enough. The latter can be observed by probing the membrane displacement. In this experiment the membrane thus acts as a sensitive detector for the collective atomic-light interactions, demonstrating the possibilities of the hybrid system for sensing and signal transduction.

Q 57: Ultracold Atoms II

Time: Friday 14:30–16:30 Location: P 104

Q 57.1 Fri 14:30 P 104

Realization of a dual-species MOT for dysprosium and potassium — •C. Ravensbergen[1,2], S. Tzanova[1,2], M. Kreyer[2], E. Soave[2], A. Werlberger[2], V. Corre[1,2], E. Kirilov[2], and R. Grimm[1,2] — [1]IQOQI, Austrian Academy of Sciences, Innsbruck, Austria — [2]Insitute for Experimental Physics, University of Innsbruck, Innsbruck, Austria

We report on the first realization of a dual-species magneto-optical trap that combines strongly magnetic lanthanide atoms (Dy) with an alkali species (K). Advanced cooling techniques in the form of narrow-line laser cooling and grey-molasses cooling give us favorable starting conditions to reach quantum degeneracy. With fermionic and bosonic isotopes of both species, our system offers a great wealth of isotopic mixtures. We are particularly interested in new Fermi-Fermi mixtures. These are expected to exhibit exotic quantum phases and novel pairing mechanisms, including for example mass-imbalanced pairing or a fermionic superfluid with a Fermi surface modified by the dipolar interactions.

Q 57.2 Fri 14:45 P 104

Towards a Perpetual Bose-Einstein Condensate — •Shayne Bennetts, Chun-Chia Chen, Benjamin Pasquiou, and Florian Schreck — Institute of Physics, University of Amsterdam, Amsterdam, The Netherlands

Production of Bose-Einstein condensates (BECs) has always been a two stage process, first laser cooling a gas sample, then cooling evaporatively until degeneracy is reached. As a result, BECs and devices based on BEC such as atom lasers are pulsed. Applications like atom interferometers would benefit greatly from a perpetual source of condensate. We are developing such a perpetual source in which we separate the cooling stages in space rather than time and protect the condensate from scattered photons using distance, baffles and a "transparency" beam. We have now demonstrated a perpetual MOT of 2×10^9 ^{88}Sr atoms with temperatures as low as 20μK on a 7.4-kHz wide laser cooling transition with a continuous loading rate of 7×10^8 atoms/s. Using a different set of parameters and location we have also demonstrated a perpetual MOT of 2×10^8 ^{88}Sr at 2μK with a loading rate of 9×10^7 atoms/s which we have successfully loaded into a dipole trap. By switching to the 0.5% abundance ^{84}Sr isotope we are able to evaporate to BECs of 3×10^5 ^{84}Sr atoms. Critically, for the second location we have validated the effectiveness of our architecture in protecting a BEC from scattered broad-linewidth laser cooling light, which is used in the first cooling stages. These are crucial steps towards demonstrating a perpetual BEC and atom laser.

Q 57.3 Fri 15:00 P 104

Optimization of modulation transfer spectroscopy on the rubidium D2 line — •Tilman Preuschoff, Patrick van Beek, Florian Ehmann, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Highly stable laser sources with narrow linewidths are of great importance for experiments in the field of atom physics. Frequency-stabilized external-cavity diode lasers are a cost efficient and compact realization of suitable sources. Sub-Doppler spectroscopy techniques provide high resolution atomic references. Among them, the modulation transfer spectroscopy (MTS) scheme is significant due to the non-linear four-wave-mixing transfer process which offers a particularly high accuracy and signal bandwidth.

We present recent experimental and theoretical investigations of the MTS technique on the ^{85}Rb D2 line in an AOM-based setup. The obtained line shape is in good agreement with the theoretical description. Numerical simulations show that an optimal combination of signal amplitude and slope at the reference frequency is achieved in the regime of high modulation indices and frequencies. Within the experimentally available parameter regime this optimum is accessible. We demonstrate a frequency stabilization providing an effective linewidth below 200 kHz and a long-term stability better than 100 kHz in 15 h. The MTS scheme is compared to the frequency modulation spectroscopy scheme implemented in a similar optical setup based on inexpensive DDS signal generation and standard lock-in techniques.

Q 57.4 Fri 15:15 P 104

Nonergodic diffusion of single atoms in a periodic potential — •Daniel Adam[1], Farina Kindermann[1], Andreas Dechant[2], Tobias Lausch[1], Daniel Mayer[1], Felix Schmidt[1], Steve Haupt[1], Michael Hohmann[1], Nicolas Spethmann[1], Eric Lutz[2], and Artur Widera[1] — [1]TU Kaiserslautern, Department of Physics, Kaiserslautern, Germany — [2]Friedrich-Alexander-Universität, Department of Theoretical Physics, Erlangen, Germany

Diffusion is ubiquitous in nature, and related models are essential to many fields in science, technology and society, including life sciences, traffic or financial market theory. The most prominent model for diffusion is Brownian motion. The hallmarks of this are a linearly increasing mean squared displacement (MSD); a Gaussian distributed step distance distribution; a stationary value for the autocorrelation function of single particle trajectories; and established ergodicity. Here, we engineer a system of a single atom in a periodic potential, which is coupled to a photon bath. We observe diffusion of the atom in the lattice, driven by random photon scattering events. While the dynamics exhibits a linear increase of the MSD for all times, we find that ergodicity is not established even for long timescales. Moreover, we observe a different timescale on which the step distribution approaches Gaussianity. Our experimental results for equilibrium systems are in excellent agreement with analytical predictions of a continuous time random walk model with exponential distance and waiting time distribution. Our results may be helpful for the interpretation of related observations in biological systems.

Q 57.5 Fri 15:30 P 104

Measuring correlations of cold-atom systems using multiple quantum probes — •Michael Streif[1,2], Andreas Buchleitner[2], Dieter Jaksch[1,3], and Jordi Mur-Petit[1] — [1]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [3]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, 117543 Singapore

The remarkable advances in experiments with ultracold bosonic atoms in optical lattices have triggered several possibilities to study the physics of many-body quantum systems. A common issue in most experiments is the destructive nature of the measurement method. For this reason, in recent times, ancillary quantum systems have been used as quantum probes. We here present a non-destructive method to probe a complex quantum system using multiple impurity atoms as quantum probes. It is demonstrated that non-local two-point correlation functions can be determined by accessing a coherence element of the density matrix of the impurities. In particular, for contact interactions between probes and system, our protocol yields the many-body density-density correlation function.

Q 57.6 Fri 15:45 P 104

Cavity-induced quantum phases of ultracold atoms in commensurate potentials — •Benjamin Bogner, Giovanna Morigi, and Heiko Rieger — Theoretical Physics Saarland University, 66123 Saarbrücken, Germany

We analyse the quantum phases of bosonic atoms, which are tightly confined by a one-dimensional optical lattice and interact with the long-range potential induced by the coupling with an optical resonator. Their dynamics is described by an extended Bose-Hubbard model, where the cavity field induces long-range density-density interactions in the form of the square of the even-odd site occupation balance. The interplay of this potential with nearest neighbor hopping and onsite repulsion is analyzed by means of quantum Monte-Carlo simulations. The phase diagram is determined as a function of the hopping amplitude, the chemical potential, and the strength of the long-range cavity interaction, rescaled by the onsite potential strength, displaying superfluid, supersolid, Mott insulator, and density-wave regions phases. A comparison is drawn with the phase diagram of the extended one-dimensional Bose-Hubbard-model with only nearest-neighbour interactions.

Q 57.7 Fri 16:00 P 104

Semiclassical theory of synchronization-induced cooling — •Simon B. Jäger[1], Stefan Schütz[1,2], Minghui Xu[3,4], Jinx Cooper[3,4], Murray J. Holland[3,4], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]icFRC, IPCMS (UMR 7504), ISIS (UMR 7006), Université de Strasbourg and CNRS, 67000 Strasbourg, France — [3]JILA, National Institute of Standards and Technology and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA — [4]Center for Theory of Quantum Matter, University of Colorado, Boulder, Colorado 80309, USA

We analyse the cooling dynamics of the motion of atoms confined inside an optical cavity, in the regime in which the atoms are incoherently pumped and the dipoles can synchronize. Our study is performed in the semiclassical regime and assuming that cavity decay is the largest rate characterizing the dynamics. We show that the cooling dynamics consists of three regimes. First hot atoms are individually cooled by the cavity friction forces. After this stage, motion and internal degrees of freedom evolve and the motion is further cooled until the dipoles synchronize. In this latest stage, when the dipoles are sychronized dipole-dipole correlations are stationary and the motion is further cooled to temperatures which are limited by the pump rate. In this regime spin and atomic position are correlated, such that the internal excitations oscillate spatially with the cavity standing wave forming an effective antiferromagnetic order. We discuss the limits of the semiclassical treatment and its extension to a full quantum mechanical model.

Q 57.8 Fri 16:15 P 104

Sympathetic cooling of quantum simulators — •Meghana Raghunandan and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover

We discuss the possibility of maximizing the cooling of a quantum simulator by controlling the system-environment coupling such that the system is driven into the ground state. We make use of various analytical tools such as effective operator formalism [1] and the quantum master equations to exactly solve the model of an Ising spin chain consisting of N particles coupled to a radiation field. We maximize the cooling by finding the dependence of the effective rate of transitions of the various excited states into the ground state. We show that by adding a single dissipative qubit, we already get quite substantial cooling rates.

[1] Effective operator formalism for open quantum systems. Phys. Rev. A 85, 032111

Q 58: Quantum Gases: Fermions III

Time: Friday 14:30–16:30 Location: P 204

Q 58.1 Fri 14:30 P 204

Spin chains of strongly interacting one-dimensional multicomponent gases — •Frank Deuretzbacher[1], Daniel Becker[2], Johannes Bjerlin[3], Stephanie Reimann[3], and Luis Santos[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstrasse 2, 30167 Hannover — [2]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstrasse 9, 20355 Hamburg — [3]Mathematical Physics and NanoLund, LTH, Lund University, SE-22100 Lund, Sweden

Strongly interacting one-dimensional multicomponent gases form spin chains without the need for an optical lattice [1,2]. Such spin chains have been realized in Selim Jochim's group in Heidelberg with few two-component fermions [3]. The spin configurations of the spin chains may be detected through tunneling measurements and measurements of the occupancies of the single-particle trap levels and of the momentum distributions [4]. Finally, we show that strongly interacting one-dimensional Bose-Fermi mixtures form tunable XXZ spin chains [5]. The various phases of the XXZ model may be realized by tuning the interactions between the bosons and the bosons and fermions independently.

[1] F. Deuretzbacher *et al.*, Phys. Rev. Lett. 100, 160405 (2008)
[2] F. Deuretzbacher *et al.*, Phys. Rev. A 90, 013611 (2014)
[3] S. Murmann *et al.*, Phys. Rev. Lett. 115, 215301 (2015)
[4] F. Deuretzbacher *et al.*, Phys. Rev. A 94, 023606 (2016)
[5] F. Deuretzbacher *et al.*, arXiv:1611.04418 (2016)

Q 58.2 Fri 14:45 P 204

Revealing "hidden" antiferromagnetic correlations in hole-doped Hubbard chains via string correlators — •Timon Hilker[1], Guillaume Salomon[1], Martin Boll[1], Ahmed Omran[1], Jayadev Vijayan[1], Joannis Koepsell[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institute für Quantenoptik, Garching — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, München

In 1D quantum many-body systems the elementary excitations split into an independent spin and density sector. A microscopic observation of this phenomenon is so far elusive. Here we report on the observation of a striking consequence of spin-charge separation in 1D Fermi-Hubbard chains via the full measurement of both spin and density distributions. Our analysis in terms of string operators reveals "hidden" antiferromagnetic spin correlations masked by the holes in the doped system in direct analogy to hidden order in spin-1 Haldane chains. This allows us to restore Heisenberg correlations in the spin sector of the system independent of the density sector by studying "squeezed space", which effectively removes the holes separating the spins.

Our measurements demonstrate the power of quantum gas micro-

scopes for the study of doped Hubbard systems that can be directly transferred to two dimensional systems.

Q 58.3 Fri 15:00 P 204

Transport of ultracold fermions through a mesoscopic one-dimensional lattice — •Martin Lebrat[1], Dominik Husmann[1], Samuel Häusler[1], Laura Corman[1], Sebastian Krinner[1], Pjotrs Grišins[2], Thierry Giamarchi[2], Jean-Philippe Brantut[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zürich, Switzerland — [2]Department of Quantum Matter Physics, University of Geneva, 1211 Genève, Switzerland

Conductance is one of the simplest measurable quantities revealing the conducting or insulating nature of a physical system, and yet an intricate non-local property sensitive to quantum interferences at a microscopic level. In our cold-atom setup, such a conductance measurement can be performed by connecting two macroscopic reservoirs of ultracold fermions to a smaller structure engineered by light potentials, and probing the current created by a atom number difference between the reservoirs.

In this talk, we report on the transport of degenerate ^{6}Li atoms through a structure tailored in a bottom-up approach: using a Digital Micromirror Device to project up to nine consecutive scatterers inside a one-dimensional constriction, a lattice can be formed one site at a time. We observe the emergence of a band gap, originating from interferences among the scatterers. The coherent character of transport can be investigated by independently changing the lattice length and the temperature. The presence of a gap is robust against attractive interparticle interactions, hinting at the persisting fermionic character of the strongly correlated gas present in the 1d lattice.

Q 58.4 Fri 15:15 P 204

Measuring density and spin correlations in the two dimensional Hubbard model — •Jan Henning Drewes[1], Luke Miller[1,2], Eugenio Cocchi[1,2], Chun Fai Chan[1], Nicola Wurz[1], Marcell Gall[1], Daniel Pertot[1], Ferdinand Brennecke[1], and Michael Köhl[1] — [1]Physikalisches Institut, University of Bonn, Wegelerstrasse 8, 53115 Bonn, Germany — [2]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE, United Kingdom

We experimentally study the emergence of correlations between ultracold fermionic atoms in a two dimensional optical lattice. For strong interactions and low temperatures from a comparison of local density fluctuations and thermodynamic quantities we observe the suppression of non-local density correlations indicating the localization of atoms in the Mott insulator. In the spin sector we observe the emergence of anti-ferromagnetic spin correlations and determine the uniform magnetic susceptibility of the two-dimensional Hubbard model from simultaneous in-situ absorption imaging of both spin components. At half filling and strong interactions our data can be described by the Heisenberg model of localized spins with anti-ferromagnetic correlations. Moreover, utilizing control over the trap shape we are able to engineer the entropy distribution within the system.

Q 58.5 Fri 15:30 P 204

Modulation spectroscopy of ultracold fermions in optical superlattices — •Karla Loida, Jean-Sébastien Bernier, and Corinna Kollath — Uni Bonn, Nussallee 14-16, 53115 Bonn

We study the excitation spectrum of the ionic Hubbard model. The ionic Hubbard model consists of three terms: a nearest-neighbor tunneling, an onsite interaction and an alternating energy offset between even and odd sites. It was originally introduced for the description of condensed matter systems, e.g. mixed stacked organic compounds, and can be cleanly realized by ultracold fermionic atoms confined to an optical superlattice. Its phase diagram in one dimension has attracted considerable theoretical interest. In the limits of predominating energy offset or onsite interaction strength, the ground state is a band insulator or Mott insulator, respectively. In between a narrow so-called bond-ordered wave phase has been predicted which spontaneously breaks site-inversion symmetry. The excitation spectrum of the ionic Hubbard model has attracted much less attention so far. We exert a time-periodic modulation and study the exact time-dependence in different phases within the time-dependent density matrix renormalization group method. Our study is motivated by the possibilities of experimental probing in cold atomic gas experiments where our choice of perturbation corresponds to lattice amplitude modulation spectroscopy of superlattice geometry.

Q 58.6 Fri 15:45 P 204

Quantum simulation of strong field phenomena in optical lattices — •Nikodem Szpak — Faculty of Physics, University of Duisburg-Essen, Germany

Ultracold atoms in optical lattices present a fascinating possibility of studying strong field phenomena for analogue quantum fields, usually not accessible in direct experiments. We review the methods used for the design of such optical systems with tailor made effective properties as well as possible observables. We concentrate on preparation of optical lattices with position and time-dependent tunneling parameters for creation of extremely strong electromagnetic and gravitational fields and on the possibilities of simulation of dynamical and spontaneous pair creation.

Q 58.7 Fri 16:00 P 204

Detecting topological order in finite-temperature and driven dissipative systems — •Dominik Linzner and Michael Fleischhauer — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany

We propose a conceptual detection scheme of topological invariants for thermal and driven, dissipative gaussian systems. In closed systems topological order can be measured by means of quantized transport which coincides with a quantized winding of the polarization. This connection breaks down for mixed states, e.g. in the presence of a finite temperature. While in previous work [1] we have identified that the winding of the polarization is still quantized in open systems and can therefore be used to classify topological order, the same no longer holds true for transport properties. We show, however, that an auxiliary system at T≈0 coupled to the finite-temperature or driven system can inherit its topological properties. Thus a non-trivial winding of the polarization in the open system leads to a quantized particle transport in the auxiliary system. This allows us to detect topological order in open systems. [1] D. Linzner, L. Wawer, F. Grusdt and M. Fleischhauer, Phys. Rev. B **94**, 201105(R) (2016)

Q 58.8 Fri 16:15 P 204

Thermoelectric effects at an atomic quantum point contact — •Laura Corman, Dominik Husmann, Martin Lebrat, Samuel Häusler, Jean-Philippe Brantut, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Thermoelectricity describes the phenomenon by which a temperature gradient triggers the appearance of a chemical potential gradient and vice versa. It is of great technological importance for cooling materials (Peltier effect) or power generation (Seebeck effect), but it is also a fundamental probe of the physics of the medium in which the energy and particle currents are created. Thermoelectric effects have already been studied with cold atoms using a two-dimensional constriction [1].

In this presentation, we experimentally study those effects on our mesoscopic transport setup using ultracold fermionic lithium. These effects are affected by the properties of both the constriction and the reservoirs. First, we reduce the dimensionality of the constriction: two temperature imbalanced reservoirs are connected via a one to few mode channel, which is similar to the condensed matter quantum point contact systems. In addition, we can vary the interaction strength to reach the strongly interacting, unitary regime where the evolution of particle and energy currents are strongly modified compared to the weakly interacting case.

[1] J.P. Brantut, et al. "A thermoelectric heat engine with ultracold atoms." Science 342(6159), 713-715 (2013).

Q 59: Ultracold atoms and BEC - VI (with A)

Time: Friday 14:30–16:00 Location: N 1

Invited Talk Q 59.1 Fri 14:30 N 1
Sympathetic cooling of OH- by means of a heavy buffer gas — •Henry Lopez[1], Bastian Höltkemeier[1], Jonas Tauch[1], Tobias Heldt[1], Eric Endres[2], Roland Wester[2], and Matthias Weidemüller[1] — [1]INF 226, 69120 Heidelberg — [2]Technikerstraße 25/3, 6020, Innsbruck

Sympathetic cooling is a versatile tool that is used when other standard cooling methods like laser cooling are not applicable. In the last few years there has been a big debate about its limitations under certain circumstances: is it possible to cool down trapped ions in a system where the coolant is heavier than the cooled particle? By using a spatially confined buffer gas * e.g. a magneto optical trap - for atoms and a high-order radio frequency trap for ions, we have theoretically shown that sympathetic cooling of ions in such hybrid systems becomes feasible. In order to proof this experimentally we are developing a novel hybrid atom-ion trap. As buffer gas we use an ultracold cloud of Rb atoms confined in a dark spontaneous-force optical trap loaded from a 2D-MOT. The ions, in particular OH-, are stored in an 8-pole rf trap made of thin wires, guaranteeing optical access into the trapping region. For probing the temperature of the ions we apply electron-photodetachment tomography of the negative ions. In this talk I report on the latest experimental results, the status of our experiment, its limitations and possible applications.

Q 59.2 Fri 15:00 N 1
In-situ charge control of a silica optical nanofiber in an ion trap — •Benjamin Ames[1], Johannes Ghetta[1], Jan Petersen[2], Philip Holtz[1], Kirill Lakhmanskiy[1], Michael Brownnutt[3], Florian Ong[1], Arno Rauschenbeutel[2], Yves Colombe[1], and Rainer Blatt[1,4] — [1]Institut für Experimentalphysik, University of Innsbruck, Innsbruck, Austria — [2]TU Wien, Wien, Austria — [3]University of Hong Kong, Pokfulam, Hong Kong — [4]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria

A trapped ion confined within the evanescent field of an optical nanofiber could be a novel ion-photon interface for networking quantum information between registers. However, achieving the sub-micron ion-fiber distance required to observe coupling to the evanescent field remains problematic due to charges on the nanofiber surface. We report on in-situ techniques developed to mitigate the charge of the nanofiber. Using photoemission and anomalous field emission we are able to charge the fiber positively, while both positive and negative states can be obtained by means of electron flooding at different energies. These results can be applied to a variety of AMO experiments where charge control of dielectrics is desired.

Q 59.3 Fri 15:15 N 1
Commensurate-incommensurate transition with ions — •Andreas Alexander Buchheit[1], Haggai Landa[2], Cecilia Cormick[3], Thomas Fogarty[4], Vladimir Stojanovic[5], Eugene Demler[5], and Giovanna Morigi[1] — [1]Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]LPTMS, CNRS, Univ. Paris-Sud, Université Paris-Saclay, 91405 Orsay, 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 show that the commensurate-incommensurate transition can be simulated with a trapped linear chain of ions which are additionally confined by an optical lattice. The ratio between the ion interparticle distance in the absence of the lattice and the lattice wavelength can be adjusted by modifying the ion trapping potential, and we focus on the regime when these two lengths are nearly commensurate. We show that in this system one can observe the onset of the incommensurate phase through the creation of solitons at the chain edges followed by the formation of a soliton chain, and we further identify the range of ion temperatures and chain sizes which allows these dynamics to be realised. We finally discuss the observables which signal the inception of this phase and the regime of experimental parameters for which these dynamics can be observed.

Q 59.4 Fri 15:30 N 1
Excitation and Transport of Discrete Solitons in Coulomb Crystals — •Jonathan Brox[1], Philip Kiefer[1], Miriam Bujak[1], Haggai Landa[2], and Tobias Schaetz[1] — [1]Atom-, Molekül- und optische Physik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]LPTMS, Université Paris Sud, Orsay, France

We study structural defects (kinks), which are formed in 2D Coulomb crystal [1].

Ion crystals with such structural defects feature localized modes in the vibrational spectrum[2]. We show that resonant excitation of kinks leads to a directed transport conditional on the conformation of the topological protected defect inside the ion crystal [3].

[1] M. Mielenz et al., Phys. Rev. Lett. **110**, 133004 (2013)
[2] H. Landa et al., New J. Phys. **15**, 093003 (2013)
[3] J. Brox et al., publication in preparation

Q 59.5 Fri 15:45 N 1
Strong Backscatterer at the Edge of a Two-dimensional Topological Insulator — •Junhui Zheng[1,2] and Miguel A. Cazalilla[2] — [1]Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt/Main, Germany — [2]Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan

We study the problem of a backscattering impurity coupled to the edge states of a two-dimensional topological insulator. In the regime where the backscattering potential is larger than the band gap and accounting for electron-electron interactions, it is shown that the system can be described as a resonant level coupled to the one-dimensional (1D) channel of interacting edge electrons. We discuss the relationship of this system to the model of a (structureless) impurity in a 1D interacting electron liquid. Different from the latter model, in the resonant regime transmission is suppressed also for weak to moderately attractive interactions.